November 24, 2020

Aircraft Performance Group Study

I. ACCIDENT

NTSB Number:	DCA20MA002
Location:	Thomas Madsen Airport (DUT), Unalaska, Alaska
Date:	October 17, 2019
Time:	1740 Alaska Daylight Time
Aircraft:	Saab 2000, N686PA
Operator:	Peninsula Aviation Services, Incorporated d.b.a. PenAir

II. VEHICLE PERFORMANCE GROUP

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1.0 INTRODUCTION

On October 17, 2019, about 1740 Alaska Daylight Time, PenAir flight 3296, a Saab 2000, N686PA, overran the runway while landing at the Thomas Madsen Airport (DUT), Unalaska, Alaska.[1] The airplane was making its second landing approach when it touched down on runway 13 and overran the runway, passing through the airport perimeter fence, crossing a road, and then pitching down over shoreline rocks. The airplane came to rest with the main landing gear wheels at the top of the rocks and the nose wheels in the water. Of the 39 passengers and 3 flight crew on board, 1 passenger was fatally injured, 4 passengers sustained injuries, and 37 passengers and flight crew were uninjured. Visual meteorological conditions prevailed. The airplane was substantially damaged. The airplane was operating as a regularly scheduled passenger flight in accordance with the provisions of *14 Code of Federal Regulations Part 121* from Ted Stevens International Airport (ANC), Anchorage, Alaska to DUT.[2]

An aircraft performance group was formed in mid-December 2019 to evaluate the accident airplane energy management, expected deceleration capability, and actual deceleration capability. The group convened in person at a Saab facility in Linköping, Sweden in February 2020 to discuss the factual evidence, the calculated landing distances as a function of reverse thrust and anti-skid brake system configuration, and Saab 2000 developmental and certification flight test data. The balance of group business was conducted via email, teleconference calls, and webcast meetings. The aircraft performance study results indicate that N686PA should have had the landing performance capability to stop within the runway 13 landing distance available (LDA) or the declared distance runway safety area (RSA).

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[1] The airplane was owned and operated by Peninsula Aviation Services, Incorporated d.b.a. PenAir.

[2] ANC is the FAA identifier and PANC is the ICAO identifier for Ted Stevens International Airport, Anchorage, Alaska. DUT is the FAA identifier and PADU is the ICAO identifier for Thomas Madsen Airport, Unalaska, Alaska.

2.0 METHOD

This aircraft performance study provides comprehensive, data-driven, quantified assessments of expected Saab 2000 landing performance capability and identifies positive or negative factors that contributed to the observed N686PA stopping performance. The study is based on available N686PA factual evidence and Saab 2000 aerodynamics, engine, and brake system data that Saab engineering and flight test/operations staff used to develop, test, and validate landing performance (and other engineering) models; construct the Aircraft Operations Manual (AOM), Aircraft Flight Manual (AFM), and Quick Reference Handbook (QRH); and certify the airplane. All of the Saab foundational factual data and models used in this study predated the accident.

Saab did not construct or maintain a Saab 2000 desktop engineering simulation capability for all flight phases or a Saab 2000 pilot-in-the-loop engineering simulation capability. These broader simulation tools are not needed to complete the NTSB aircraft performance group tasks. The group discussed Saab 2000 landing performance model limitations; applicable flight test data; operational and engineering assumptions; trained and planned operational versus actual procedures and techniques; time of arrival landing distance assessment data and practices; available landing safety margin; event environmental conditions; airplane weight and balance; touchdown energy state; air, transition, and rollout distance modeling; and landing deceleration device configuration, including application sequence, timing, settings, and duration.

A review of the available Flight Data Recorder (FDR), Cockpit Voice Recorder (CVR), Appareo Stratus Global Positioning System (GPS) device, and passenger video factual evidence indicated that the N686PA main landing gear (MLG) touched down on the runway 13 touchdown target zone about 1,100 feet beyond the runway 13 threshold, on centerline.[3] The airplane configuration and energy state at MLG touchdown defined the initial condition for this study. The study scope is primarily from airplane MLG touchdown to the position at which the airplane stops on, or departs from, the improved pavement surface, which includes the RSA and blast pad.

2.1 N686PA Weight and Balance

The N686PA weight and balance at time of arrival was calculated using data from the PenAir maintenance records, the PenAir flight 3296 load manifest and flight from Anchorage, Alaska (ANC) to Unalaska, Alaska (DUT), and the Saab 2000 Weight and Balance Manual (WBM).[4]

2.2 Saab 2000 Aircraft Flight Manual (AFM) Limitations

The following operational limits were extracted from the Saab 2000 AFM for convenient reference:

Airport pressure altitude limits

1000 ft below sea level to 8000 ft above sea level (-1000 ft to +8000 ft)
For operation with ENG BLD ON, see Section 5-2.

Maximum tailwind for take- off and landing

For -1000 to +6000 ft pressure altitude: 15 kts
For pressure altitude above 6000 ft: 10 kts

NOTE: The capability of the airplane has been satisfactorily demonstrated for takeoff and manual landing with tailwinds up to 15 knots. Each individual operator must apply to the appropriate airworthiness authority for operational approval of tailwind operation in excess of 10 knots.

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[3] N686PA MLG touchdown evidence is provided in the Aircraft Performance Group Crash Site Factual, sections 2.5 and 2.8.

[4] A reproduction of the PenAir maintenance record that documents the N686PA Operating Empty Weight (OEW) and balance is included in the Aircraft Performance Group Crash Site Factual, section 2.11. The PenAir load manifest and flight plan for flight 3296 are available in the NTSB Operational Factors/Human Performance Factual, Attachment 4.

Maximum crosswind component (including gust)

Without Mod. No 5791 (Modified aileron system) installed: 26 knots

With Mod. No 5791 installed: See Section 5-2.

Maximum runway slope for take- off and landing

-2.0 % to +2.0 %

2.3 PADU Runway 13/31

Runways 13 and 31 are constructed of grooved asphalt and each have displaced thresholds to accommodate their respective 300-foot declared distance RSAs. Runway 13 has a published LDA of 3,900 feet which does not include the adjoining RSA or the 140-foot paved blast pad. An excerpt of the existing DUT airport layout plan is shown in Figure 1 with annotations denoting the runway 13 turnoff point, RSA, and the blast pad for runway 31.

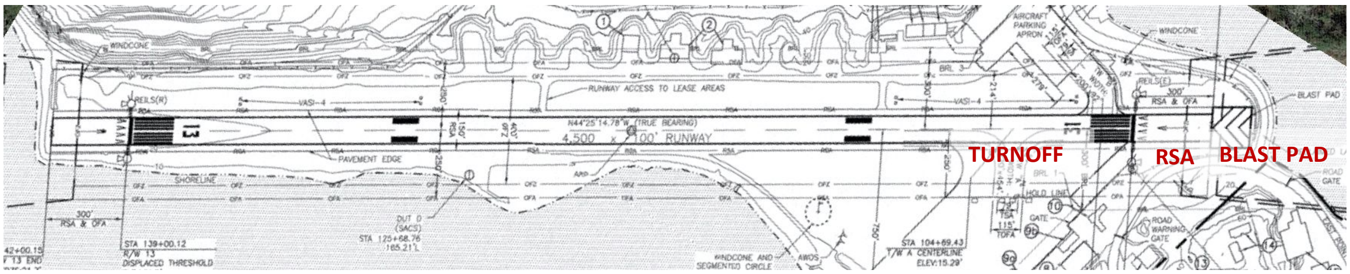

Figure 1: Excerpt of existing airport layout plan (DUT). N686PA travel direction was left to right on runway 13.

2.4 Weather

The following meteorological content was extracted from the NTSB Weather Study for convenient reference:

[1656 AKDT]	**METAR PADU 180056Z 31011KT 10SM FEW034 BKN047 BKN060 07/01 A2950 RMK AO2 SLP995 T00720011=**
[1756 AKDT]	**METAR PADU 180156Z 30021G27KT 5SM -RA BKN039 06/02 A2953 RMK AO2 PK WND 30027/0154 RAB41 SLP004 P0002 T00560017=**

A METAR is an aerodrome meteorological report that documents hourly surface weather observations. At 1656 AKDT, the PADU Automated Weather Observing System (AWOS) reported a wind from 310° at 11 knots, visibility of 10 statute miles or greater, few clouds below 3,400 feet above ground level (agl), ceiling broken at 4,700 feet agl, broken clouds at 6,000 feet agl, temperature of 7° Celsius (C) and a dew point temperature 1°C, altimeter setting of 29.50 inches of mercury; remarks: station with a precipitation discriminator, sea-level pressure of 999.5 hectopascals (hPa), temperature of 7.2°C and dew point temperature of 1.1°C.

At 1756 AKDT, the PADU AWOS reported a wind from 300° at 21 knots with gusts to 27 knots, visibility of 5 statute miles, light rain, ceiling broken 3,900 feet agl, temperature of 6°C and dew point temperature of 2°C, altimeter setting of 29.53 inches of mercury; remarks: station with a precipitation discriminator, peak wind of 27 knots from 300° at 1754 AKDT, rain began at 1741 AKDT, sea-level pressure of 1000.4 hPa, 0.02 inches of liquid-equivalent precipitation since 1656 AKDT, temperature of 5.6°C and dew point temperature of 1.7°C.

[1740 AKDT]	**1-MIN PADU 180140Z 31020G25KT 9SM BKN039 07/02 A2952 390 70 -400 300/20G25 RMK AO2**
[1741 AKDT]	**1-MIN PADU 180141Z 31019G25KT 9SM -RA BKN039 07/02 A2952 390 70 -400 300/19G25 RMK AO2 RAB41 P0000**

> At 1740 AKDT, the PADU AWOS recorded a wind from 310° at 20 knots with gusts to 25 knots, visibility of 9 statute miles, ceiling broken at 3,900 feet agl, temperature 7°C and dew point temperature of 2°C, altimeter setting of 29.52 inches of mercury, pressure altitude of 390 feet, relative humidity of 70 percent, density altitude of -400 feet, wind from 300° magnetic at 20 knots with gusts to 25 knots; remarks: station with a precipitation discriminator. This report was not pulled by or pushed to the crew.
>
> At 1741 AKDT, the PADU AWOS recorded a wind from 310° at 19 knots with gusts to 25 knots, visibility of 9 statute miles, light rain, ceiling broken at 3,900 feet agl, temperature 7°C and dew point temperature of 2°C, altimeter setting of 29.52 inches of mercury, pressure altitude of 390 feet, relative humidity of 70 percent, density altitude of -400 feet, wind from 300° magnetic at 19 knots with gusts to 25 knots; remarks: station with a precipitation discriminator, rain began at 1741 AKDT, trace amount of liquid-equivalent precipitation since 1656 AKDT. This report not pulled by or pushed to the crew.

Available surveillance camera video evidence indicates N686PA MLG touchdown occurred prior to 1740 AKDT and the accident occurred at about 0740 AKDT. The NTSB Meteorologist summarized his communications with the NTSB Aircraft Performance Group Chairman on 11/24/2019 regarding factual weather evidence at time of arrival:

> The 1741 AKDT one-minute observation from the AWOS reported that rain had begun at 1741 AKDT and that a trace amount of liquid-equivalent precipitation had fallen since the previous hourly AWOS observation at 1656 AKDT. However, it cannot be determined at what time(s) that trace amount of liquid-equivalent precipitation had accumulated at the AWOS since 1656 AKDT. In addition, the AWOS one-minute observation at 1744 AKDT reported that at 1744 AKDT, 0.01 inches of liquid-equivalent precipitation had fallen since 1656 AKDT. This report indicates that at some time during the previous minute, the amount of accumulated liquid-equivalent precipitation collected since 1656 AKDT had reached 0.01 inches.

A supporting excerpt of the one-minute AWOS data is duplicated below. The 1741 AKDT (0141Z) one-minute AWOS entry is highlighted using the following conventions:

- The first column of time is local standard time, the **red** time is zulu time in DDHHMMZ.
- **Blue text** identifies wind direction referenced to true north (rounded to nearest 010°) with average wind and gust magnitude
- "-RA" identifies "light rain"
- **Green text** identifies wind direction referenced to magnetic north (rounded to nearest 010°) with average wind and gust magnitude
- **Purple text** indicates the amount of liquid-equivalent precipitation (straight rain in this case) accumulation since 56 minutes past the previous hour (so at 0141Z it would have been 46 minutes of accumulation). The format is PABCD, where A is tens of inches, B is ones of inches, C is tenths of inches, D is hundredths of inches, and P0000 equals "trace")

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10/17/2019 16:45:31  1-MIN PADU 180145Z 31013G25KT 9SM -RA BKN039 06/02 A2952 390 73
     -500 300/13G25 RMK AO2 RAB41 P0001
10/17/2019 16:44:31  1-MIN PADU 180144Z 32014G25KT 9SM -RA BKN039 06/02 A2952 390 73
     -500 310/14G25 RMK AO2 RAB41 P0001
10/17/2019 16:43:31  1-MIN PADU 180143Z 32017G25KT 9SM -RA BKN039 06/02 A2952 390 73
     -500 310/17G25 RMK AO2 RAB41 P0000
10/17/2019 16:42:31  1-MIN PADU 180142Z 32019G25KT 9SM -RA BKN039 06/02 A2952 390 73
     -500 310/19G25 RMK AO2 RAB41 P0000
10/17/2019 16:41:31  1-MIN PADU 180141Z 31019G25KT 9SM -RA BKN039 07/02 A2952 390 70
     -400 300/19G25 RMK AO2 RAB41 P0000
10/17/2019 16:40:31  1-MIN PADU 180140Z 31020G25KT 9SM BKN039 07/02 A2952 390 70 -
     400 300/20G25 RMK AO2
10/17/2019 16:39:31  1-MIN PADU 180139Z 31023KT 10SM BKN039 07/02 A2952 390 68 -400
     300/23 RMK AO2 PRESRR
10/17/2019 16:38:31  1-MIN PADU 180138Z 30022G25KT 10SM BKN039 07/02 A2952 390 68 -
     400 290/22G25 RMK AO2 PRESRR
```

The following meteorological content was extracted from the NTSB Weather Study – Attachment 2, PADU weather observer interview summary and office log notes from the day of the accident:

> She witnessed the accident aircraft touch down but does not recall if the runway was wet or dry, however she did not recall any standing water or puddles. She indicated that a storm was coming in about the time of the landing.

2.5 N686PA Flight Leg Reconstruction

The N686PA logbook was used to reconstruct the 28 airplane flight legs that preceded the accident flight. The results are shown in Table 1. Highlighted rows indicate N686PA landings at Unalaska, Alaska (DUT or PADU).

Table 1: N686PA flight leg reconstruction

mm	dd	yy	departure hh	departure mm	arrival hh	arrival mm	block hh	block mm	flight	origin	destination	N686PA sequence
10	17	2019	15	15	17	40	2	25	3296	ANC	DUT	Accident
10	17	2019	10	45	13	2	2	17	9285	DUT	ANC	-1
10	17	2019	7	33	10	1	2	28	9284	ANC	DUT	-2
10	16	2019	20	10	21	48	1	38	2033	PABE	PANC	-3
10	16	2019	17	30	19	2	1	32	7922	PANC	PABE	-4
10	16	2019	15	30	16	45	1	15	7921	PAFA	PANC	-5
10	16	2019	13	15	14	51	1	36	7921	PABE	PAFA	-6
10	16	2019	9	45	12	21	2	36	2030	PANC	PABE	-7
10	15	2019	18	50	20	12	1	22	2033	PABE	PANC	-8
10	15	2019	16	45	18	10	1	25	2032	PANC	PABE	-9
10	15	2019	14	53	16	12	1	19	2031	PABE	PANC	-10
10	15	2019	10	15	11	47	1	32	2030	PANC	PABE	-11
10	14	2019	0	0	0	0	0	0	3296	ANC	NO FLIGHT	-11
10	14	2019	13	13	14	16	1	3	2053	DLG	ANC	-12
10	14	2019	11	25	12	40	1	15	2052	ANC	DLG	-13
10	14	2019	9	27	10	38	1	11	2056	DLG	ANC	-14
10	14	2019	8	30	8	56	0	26	2056	AKN	DLG	-15
10	14	2019	6	54	7	56	1	2	2056	ANC	AKN	-16
10	13	2019	16	32	18	40	2	8	3287	DUT	ANC	-17
10	13	2019	13	29	15	57	2	28	3286	ANC	DUT	-18
10	13	2019	10	0	11	3	1	3	2056	DLG	ANC	-19
10	13	2019	9	8	9	34	0	26	2056	AKN	DLG	-20
10	13	2019	7	35	8	37	1	2	2056	ANC	AKN	-21
10	12	2019	16	26	18	23	1	57	3287	PADU	PANC	-22
10	12	2019	13	29	16	3	2	34	3286	PANC	PADU	-23
10	12	2019	11	20	12	23	1	3	2053	PADL	PANC	-24
10	12	2019	9	35	10	43	1	8	2052	PANC	PADL	-25
10	11	2019	14	34	16	16	1	42	2047	PASD	PANC	-26
10	11	2019	13	45	14	17	0	32	2047	PACD	PASD	-27
10	11	2019	10	26	12	34	2	8	2047	PANC	PACD	-28

2.6 Saab 2000 Stabilized Approach Criteria

There are no stabilized approach criteria published in the Saab 2000 manuals. PenAir defines the term *stabilized approach* in Section 21.6.11.1 of the General Operations Manual (GOM), Rev. 13, page 6-21, dated 10/14/19 as follows:

21.6.11.1 Stabilized Approach

a. Visual Approach - The aircraft shall be stabilized by 500 feet above the airport elevation on the final approach course.
b. IFR Approach - The aircraft shall be stabilized by 1000 feet above the airport elevation.
c. "Stabilized" Indicates:

   i. Aircraft in landing configuration
   ii. Airspeed within 10 knots of V_{FA}
   iii. Aircraft established on proper vertical and course guideline with VS<1000 fpm
   iv. Checklists complete (except Auto-Pilot disconnection)

The PenAir Company Flight Manual (CFM) states in Landings, Section 26.7.5 and Normal, Section 26.7.5.1, Rev. 4, p. 7-16, dated 7/12/17, that

> Once the aircraft is established on final approach, the aircraft's configuration should remain fixed, and only small adjustments need be made to maintain glideslope, approach speed, and trim.
>
> Stabilize the aircraft on the selected approach speed with a stabilized rate of descent. Airspeed should remain stabilized a V_{REF}, plus appropriate wind, malfunction, and/or ice increments if applicable, until crossing the runway threshold on final approach, when holding proper approach speed and glide path, the aircraft's pitch attitude relative to the ground will appear level.

The N686PA FDR data were evaluated against the PenAir stabilized approach criteria. The FDR evidence indicates that N686PA was configured at flaps 20 and gear deployed, the airspeed gradually decreased from about 145 knots at 500 feet above ground level (AGL) to about 130 knots at 50 feet AGL and decreased to about 127 knots at MLG touchdown, the aircraft was established on the course guideline, and the aircraft flight path angle during short final approach steepened to about -4° for a period of about 8 seconds. Checklist information is available in the Operational Factors/Human Performance Factual. Related checklist evidence may be available in the Cockpit Voice Recorder Factual. The N686PA descent rate was below 1,000 feet per minute (FPM) until about 120 feet AGL, when it exceeded 1,000 feet per minute for 5 seconds, as evidenced by FDR radio altitude and vertical speed parametric data recorded at 1 sample per second. Auto-pilot was disconnected at about 1,000 feet AGL.

The CVR evidence indicates N686PA received an Enhanced Ground Proximity Warning System (EGPWS) "Sinkrate, Sinkrate" aural annunciation alert but no "Pull up" warning during the short final approach to landing (not during the first approach segment that preceded the missed approach/go-around). PenAir provided the N686PA EGPWS part number to the NTSB Systems and Structures Group chairman, who confirmed that a Mark V EGPWS was installed. The supporting Honeywell EGPWS documentation indicates aircraft penetration of the outer limit of the Mark V EGPWS Mode 1, excessive descent rate boundary will generate a "Sinkrate, Sinkrate" aural annunciation alert.

The Honeywell Mark V EGPWS documentation indicates that Mode 1, Excessive Descent Rate – provides alerts for excessive descent rates with respect to altitude AGL and is active for all phases of flight. Mode 1 has outer and inner aural annunciation alert boundaries which produce "Sinkrate, Sinkrate" alerts and "Pull Up" warnings, respectively. The sinkrate outer boundary is shown in Figure 2(a) and is defined by the equation

$$\text{Radio Altitude (FT)} = -572\ \text{(FT)} - 0.6035 * \text{Altitude Rate (FPM)}$$

A 0.8 second persistence condition is implemented to reduce nuisance alerts, which means that the aircraft must penetrate the sinkrate alert outer boundary for 0.8 seconds before an alert is initiated.

Figure 2(b) illustrates the static Mode 1 inner alert boundary that corresponds to the "Pull Up" aural annunciation warning. The pull up envelope is composed of two straight lines with the respective equations:

$$\text{Radio Altitude (FT)} = -1620\ \text{(FT)} - 1.1133 * \text{Altitude Rate (FPM)} \quad [-1482\ \text{FPM} > \text{descent rate} \geq -1710\ \text{FPM}]$$
$$\text{Radio Altitude (FT)} = -400\ \text{(FT)} - 0.4 * \text{Altitude Rate (FPM)} \quad [-1710\ \text{FPM} > \text{descent rate} \geq -7125\ \text{FPM}]$$

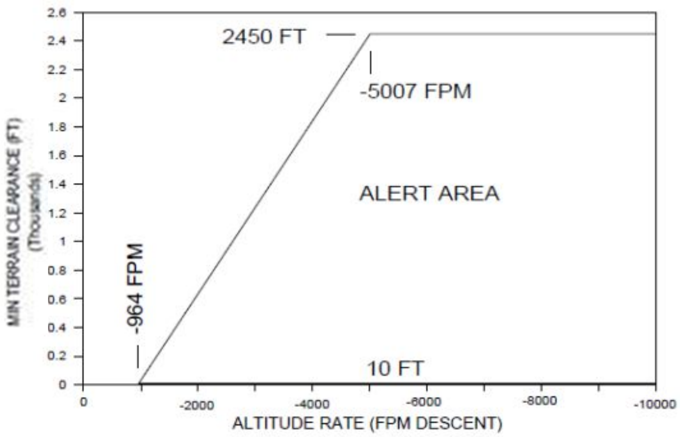

Figure 2(a): Sinkrate specification curve

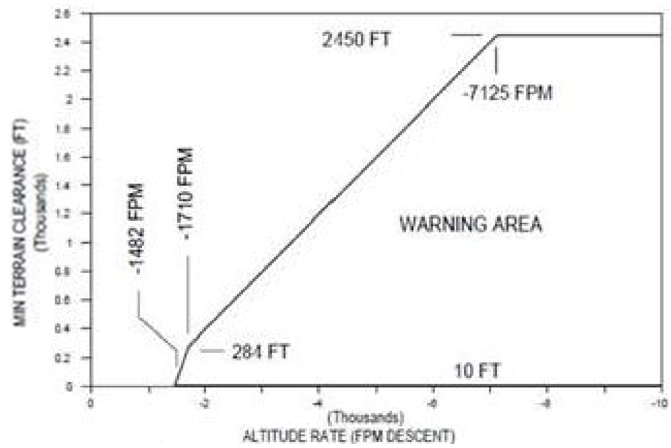

Figure 2(b): Pull up specification curve

The corresponding Mark V EGPWS Mode 1 visual and aural warnings are defined in Table 2.

Table 2: Subset of Honeywell Mark V EGPWS visual and aural warnings

Mode	Visual Warning	Aural Warning
1 – Excessive sink rate	TERRAIN lights	– SINK RATE – WHOOP WHOOP PULL UP

The N686PA FDR data were overlaid on the Honeywell Mark V EGPWS Mode 1, Excessive Descent Rate inner and outer boundaries in Figures 3(a) and 3(b). The results indicate that a Mode 1 “Sinkrate, Sinkrate” aural annunciation alert was expected during short final approach and a Mode 1 “Pull Up” aural annunciation warning was not expected.

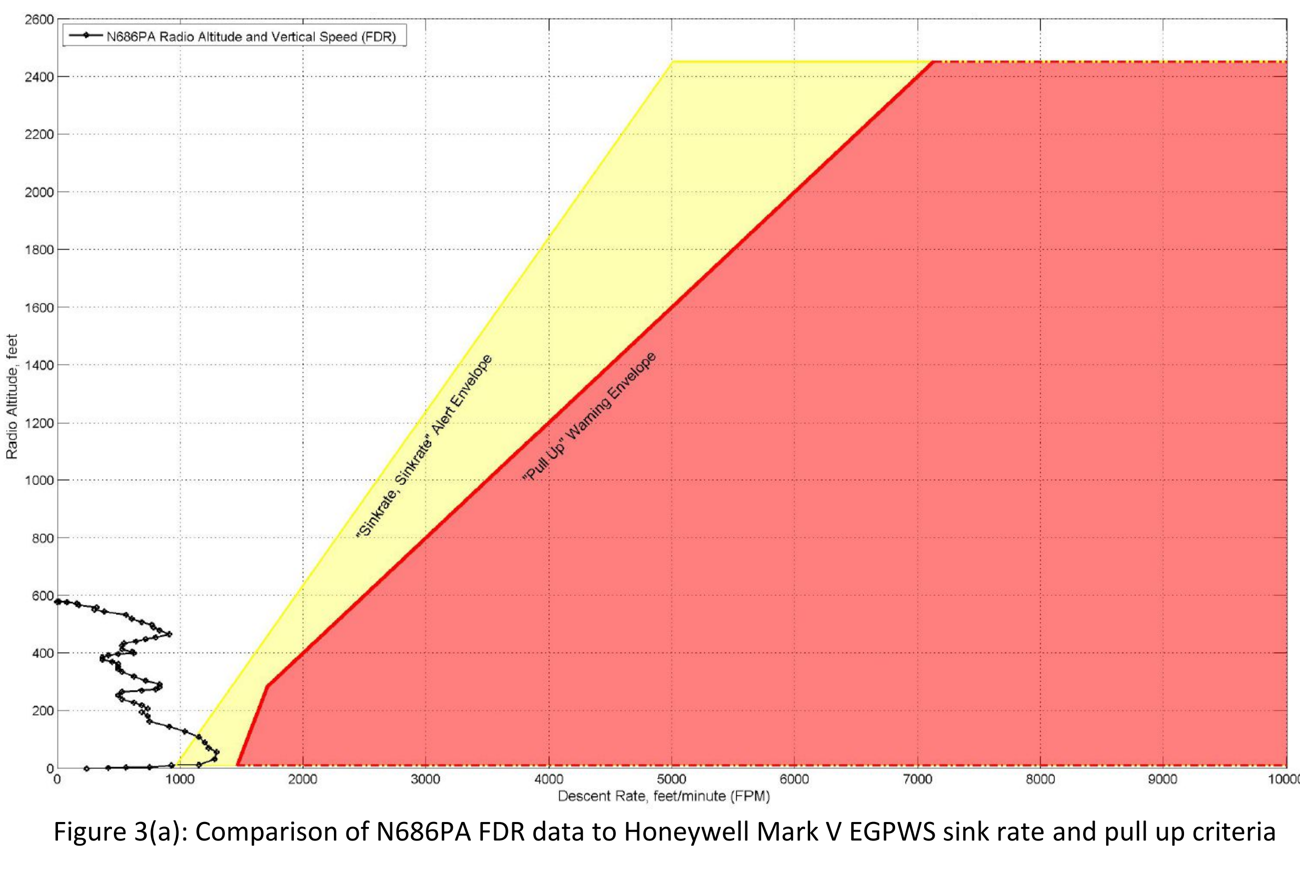

Figure 3(a): Comparison of N686PA FDR data to Honeywell Mark V EGPWS sink rate and pull up criteria

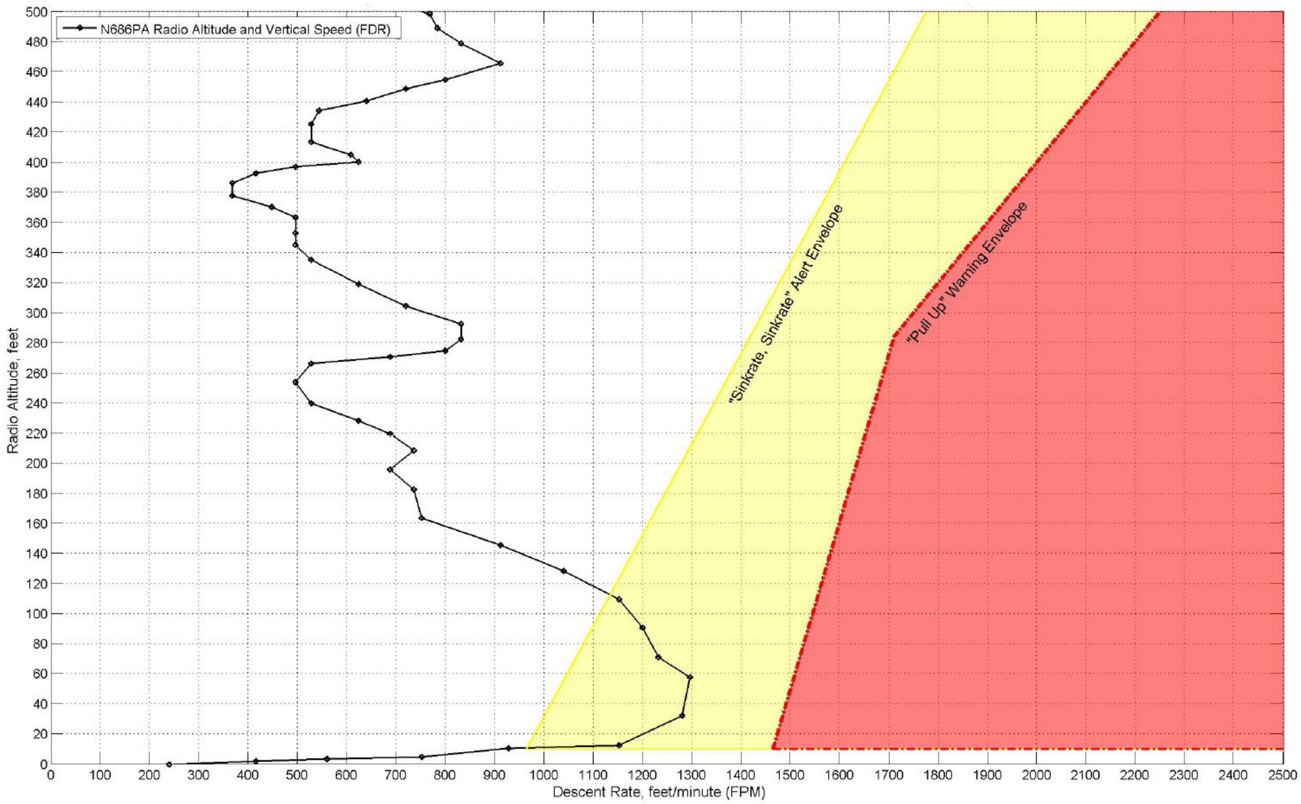

Figure 3(b): Comparison of N686PA FDR data to Honeywell Mark V EGPWS sink rate and pull up criteria (zoomed in).

2.7 PenAir Saab 2000 Arrival Procedure

A reproduction of the PenAir Saab 2000 arrival procedure for the pilot flying (PF) and the pilot monitoring (PM) is shown in Figure 4. The N686PA CVR evidence indicates that the Captain was the PF and the first officer (FO) was the PM on flight 3296.

PenAir
THE SPIRIT OF ALASKA

COMPANY FLIGHT MANUAL SAAB 2000

ARRIVAL

PAGE: 7-17
REVISION: 4
DATE: 07/12/17

Pilot Flying	Pilot Monitoring
Immediately after touchdown lower the nose wheel and retard PLs to GI.	When both BETA lights have illuminated, **"BETA"**.
At 80 KIAS.	**"80 KNOTS"**

LEFT PILOT	RIGHT PILOT
Upon hearing ***"80 Knots"*** **"BOTTOMS"** Transition to rudder and nose wheel steering (60 KIAS) for directional control. Assume PL control. By 60 KIAS move the PLs out of reverse.	Apply aileron input into the wind. Apply forward pressure on the yoke. **"TOPS"**
When exiting the runway engage the GUST LOCK.	Complete the After Landing flow when the After Landing Checklist is called for.
End of Procedure	

Figure 4: Reproduction of PenAir Saab 2000 arrival procedure

2.8 Saab 2000 Landing Performance Capability

The expected N686PA normal, unfactored landing distance was calculated using data from the Saab 2000 AFM, the Saab 2000 QRH, and the PenAir Airport Analysis Manual, the last of which was prepared by Aircraft Performance Group (APG) to support PenAir operations.[5] The normal, unfactored landing distance includes the air distance from an assumed 50-foot threshold crossing height to main gear touchdown, the distance to derotate and transition to the full deceleration device configuration, and the airplane rollout distance to a complete stop.

The central aircraft performance question is, "Does the Saab 2000 have adequate stopping performance to land at DUT on runway 13, flaps 20, 46,000 pounds, dry surface, with a 15-knot tailwind?" The supporting Saab 2000 landing performance data for Federal Aviation Administration (FAA) operations assume the airplane is equipped with automatic flap retraction (AFR) to increase main gear loading by moving flaps from 20 to 15 or 35 to 15 after touchdown, a fully functional wheel brake and anti-skid system, one engine inoperative (i.e., it produces no forward or reverse thrust), and the remaining engine at ground idle (GI) thrust during the landing rollout. The data for this configuration are conservative because the assumed landing weight is 750+ pounds greater than the estimated N686PA arrival weight of 45,213 pounds, no stopping distance credit is taken for two-engine propeller discing (reverse), and calculations for tailwinds and headwinds account for 150 percent and 50 percent of the reported wind value, respectively.

Physical evidence from two passenger videos that documented the N686PA touchdown and two stationary ground cameras that recorded the airplane departure from the runway 31 blast pad indicates that the runway 13 surface condition was bare and dry during the touchdown and landing rollout. Video evidence indicated no water on the N686PA passenger windows, no water displaced by or picked up and shed from the main landing gear wheels, no rainfall on pavement, and no rainfall on the Dutch Harbor surface prior to the airplane arriving at its final rest position. However, there was supporting video evidence of 1) N686PA propeller fragments shed and thrown into the harbor with accompanying water displacement and droplet splashing, 2) wind gusts moving across the Dutch Harbor surface, 3) adjacent sections of dry and locally wet pavement in the foreground view of a stationary camera prior to the accident, and 4) active rainfall on pavement several minutes after the accident in the foreground view of a stationary camera.

2.8.1 Saab 2000 Unfactored Landing Distance

Eighteen airplane normal landing configuration scenarios were composed from a matrix of Saab 2000 landing flap (20 or 35), wind speed (15-knot tailwind, zero wind, and 15-knot headwind), and airplane forward center of gravity limit (nominal, Alternate Forward CG I, Alternate Forward CG II) variables. Each unfactored landing distance scenario was based on a conservative airplane weight of 46,000 pounds, recorded altimeter setting of 29.50 inches Hg, recorded temperature of 8°C, and the published PADU runway 13 LDA of 3,900 feet. A conservative airplane arrival weight was selected in lieu of performing a weight sensitivity study to address hypothetical aircraft loading or fuel burn uncertainty.

The calculated, unfactored landing distance results are summarized in Table 3. The distance remaining values do not take credit for the runway 13 RSA or blast pad pavement lengths. The tabulated PADU runway 13 distance remaining data reflect the use of Saab 2000 flight test techniques, as opposed to the FAA-required safety margin for airplane dispatch or the use of operational landing techniques. The FAA guidance in Safety Alert for Operators (SAFO) 19001: Landing Performance Assessments at Time of Arrival, which is applicable to all *14 Code of Federal Regulations part 121, part 125, part 135, and part 91* airplane operators, advocates that, "The operational landing distance (OLD) used for a time of arrival landing assessment includes a safety margin of at least 15 percent when based on manual wheel braking."

[5] Aircraft Performance Group provides flight planning, runway analysis, and weight and balance services (see https://flyapg.com).

The results for Table 3, Case 3 indicate that N686PA would be expected to stop with about 455 feet or 11 percent of runway remaining (about 5 airplane fuselage lengths) before it entered the RSA, assuming the flight crew accomplished threshold crossing speed, main gear touchdown, derotation, and wheel brake application similar to the techniques and schedules embedded in the underlying Saab 2000 demonstrated distance data. The physical evidence and witness statements indicate that the N686PA flight crew accomplished main gear touchdown in the target zone, timely derotation, manual wheel brake application, and two-engine propeller discing in GI to Max Reverse thrust throughout the airplane rollout.

Table 3: Saab 2000 unfactored landing distance as a function of flap, wind, and forward CG limit

Case	Flap	Wind, knots	Forward CG Limit	Unfactored Landing Distance, ft	Distance Remaining on PADU Runway 13		MLG TD to Stop Avg. Decel., knots/sec.	Full Braking Config. to Stop Avg. Decel., knots/sec.	Comment TW = Tailwind HW = Headwind
					feet	percent			
1	20	-15	Nominal	3,625	275	7	7.0	7.5	15-kt TW
2	20	-15	Alt. Fwd I	3,545	355	9	7.1	7.6	15-kt TW
3	20	-15	Alt. Fwd	3,455	445	11	7.1	7.7	15-kt TW, N686PA arrival
4	20	0	Nominal	2,725	1,175	30	7.2	7.9	no wind
5	20	0	Alt. Fwd I	2,640	1,260	32	7.3	8.1	no wind
6	20	0	Alt. Fwd	2,600	1,300	33	7.4	8.2	no wind
7	20	15	Nominal	2,520	1,380	35	7.3	8.1	15-kt HW
8	20	15	Alt. Fwd I	2,445	1,455	37	7.4	8.2	15-kt HW
9	20	15	Alt. Fwd	2,395	1,505	39	7.4	8.3	15-kt HW
10	35	-15	Nominal	3,300	600	15	6.7	7.4	15-kt TW
11	35	-15	Alt. Fwd I	3,200	700	18	6.8	7.5	15-kt TW
12	35	-15	Alt. Fwd	3,150	750	19	6.8	7.6	15-kt TW
13	35	0	Nominal	2,450	1,450	37	6.9	7.8	no wind
14	35	0	Alt. Fwd I	2,365	1,535	39	7.0	8.0	no wind
15	35	0	Alt. Fwd	2,335	1,565	40	7.1	8.1	no wind, N686PA dispatch
16	35	15	Nominal	2,255	1,645	42	7.0	8.0	15-kt HW
17	35	15	Alt. Fwd I	2,185	1,715	44	7.0	8.1	15-kt HW
18	35	15	Alt. Fwd	2,165	1,735	45	7.1	8.2	15-kt HW

The N686PA touchdown in the target zone, derotation, and application of wheel brake are not necessarily representative of Saab performance landing techniques used to establish the AFM demonstrated landing distances. Saab engineering staff stated that Saab 2000 demonstrated landing performance is based on a -3.5° flight path angle; main landing gear touchdown at a target descent rate of about 8 feet/second; and derotation (nose gear touchdown), ground idle engine thrust selection, and maximum manual wheel brake application with full pressure in the system within 1.8 seconds of MLG touchdown. As expected, the physical evidence shows the N686PA landing was more representative of an operational landing as described in FAA SAFO 19001 and associated Advisory Circular (AC) guidance.

The Case 15 results confirm the flight dispatch calculation, that N686PA had the landing performance capability to make a flaps 35 landing in zero wind at the estimated PADU arrival weight with Alternate Forward Center of Gravity (CG) II loading. The airplane in this hypothetical PADU arrival scenario would have stopped with about 1,560 feet or 40 percent of the 3,900-foot LDA remaining (about 17 airplane fuselage lengths) before it entered the runway 13 RSA.

From a big picture perspective, the cumulative unfactored landing distance results in Table 3 demonstrate the following Saab 2000 operational benefits:

1. A higher landing flap configuration allows the main wing to generate the necessary airplane lift at a lower airspeed. The airspeed reduction yields a lower airplane energy state at main gear touchdown, reduced energy dissipation requirements (i.e., less aerodynamic drag, wheel brake, and/or propeller discing effort), and a shorter landing distance.
2. A tailwind landing increases the airplane energy state relative to the ground whereas a headwind landing reduces the airplane energy state relative to the ground. A higher airplane energy state at main gear touchdown requires increased energy dissipation (i.e., more aerodynamic drag, wheel brake, and/or propeller discing effort), resulting in a longer landing distance.
3. Saab 2000 operations using either of the available alternate forward center of gravity limits yield a modest increase in aircraft landing weight for a given LDA or a modest reduction in landing distance for a given aircraft landing weight compared to the nominal center of gravity forward limit. The applicable Saab 2000 weight and center of gravity envelopes are shown in Figure 5. Operating at more aft center of gravity positions lowers the stall speed and the corresponding VREF speed. According to Saab engineering staff, about 2/3 of the benefit from operating at the alternate forward CG II limit is from speed reduction and 1/3 is from the weight distribution change. Alternate forward CG limit operations require flight crews to adhere to the correct VREF speeds to obtain associated weight or distance benefits.
4. A more aft center of gravity position for a tricycle landing gear arrangement increases the main gear loading. For a given wheel/pavement friction environment, increased main gear loading enables the wheel brakes and anti-skid system to generate more retarding force at the wheel/pavement interface and more efficiently dissipate airplane energy in a controlled fashion.

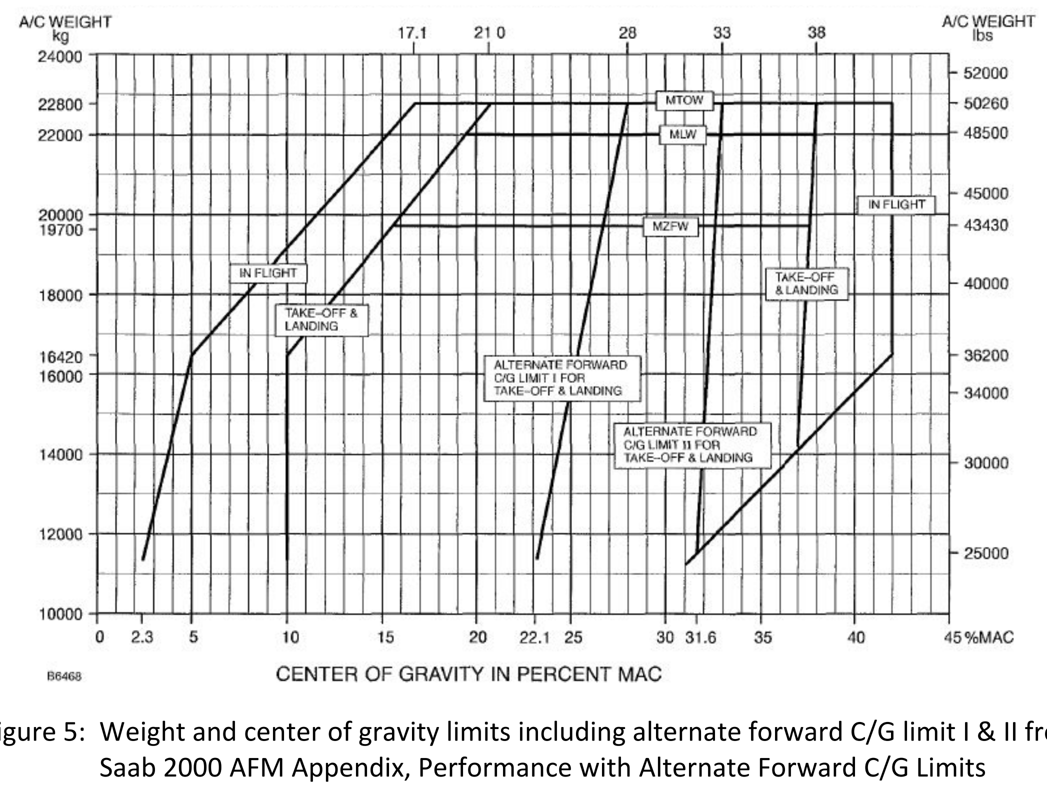

Figure 5: Weight and center of gravity limits including alternate forward C/G limit I & II from Saab 2000 AFM Appendix, Performance with Alternate Forward C/G Limits

Max zero fuel weight . . . 20,000 kg . . . 44,090 lbs Max takeoff weight . . . 22,999 kg . . . 50,700 lbs
Max taxi weight . . . . 23,200 kg . . . 51,150 lbs Max landing weight . . . 22,000 kg . . . 48,500 lbs

2.8.2 PenAir Landing Performance Data

The PenAir Saab 2000 CFM, dated 04/06/16, page 12-1, rev. 1, section 26.12 Appendix A – Saab 2000 Performance Binder refers flight crews to the Saab 2000 Performance Binder "for manufacturer performance charts and reference material from the Saab 2000 Aircraft Operations Manual." Section 26.8.6 Landing Weight, dated 06/26/18, page 8-7, rev. 5, states, "For landing information, use the 'Field Length Limits' area on the Airport Analysis." Section 26.8.6.1 Landing Calculations, also dated 06/26/18, page 8-7, rev. 5, states, "Approach and Landing Calculations: PenAir uses Airport Analysis as the primary means of calculating approach and landing weight limitations for all airports. In the event that the Airport Analysis is unavailable the Saab AFM will be utilized."

There is no evidence of engine reverse thrust credit incorporated in any of the Saab or PenAir landing performance data for FAA operations. There is a performance credit incorporated for the Automatic Flap Retraction (AFR) system modification (or absence thereof). N686PA was equipped with the AFR system.

2.8.3 PenAir Time of Arrival Landing Distance Assessments

The PenAir data and tools made available to Saab 2000 flight crews to accomplish FAA-recommended time of arrival landing distance assessments are described below. Questions were posed by the Aircraft Performance Group Chairman. Answers were provided by the PenAir acting chief pilot, Saab 2000.

Q1: *What portion(s) of the Saab 2000 QRH, AFM, and/or other documents/data are used to support flight crew time of arrival landing distance assessments?*
A1: APG Landing Charts and performance binder[6]

Q2: *How are PenAir Saab 2000 time of arrival landing distance assessments accomplished in practice? For example, reference to tables (and applicable performance adjustments) in the dispatch package; ACARS-based inputs, calculations, and ACARS results messages; electronic flight bag; worksheet; or other?*
A2: Flight crew will reference the APG manual and performance binder to assess landing speeds. The performance binder can be used to assess landing distances for runways that are contaminated. The APG manual and performance binders are on the electronic flight bag. There is no distance calculator that we can use. No ACARS or worksheets.

Q3: *What PenAir guidance and requirements were in place for Saab 2000 time of arrival landing distance assessments at the time of the accident?*
A3: The guidance that was used was the APG manual and performance binder.

Q4: *If applicable, how are PenAir Saab 2000 flight crew time of arrival landing distance assessment inputs, assumptions, and outputs recorded, archived, and retained at PenAir?*
A4: The performance numbers for landing are recorded with dispatch in the flight release, these are planned and maximum numbers. The flight crew will use the time of arrival landing weight to look up appropriate performance information from the APG manual and performance binder. They are not required to record landing distance. Speeds are also not recorded, they will be written down but the company does not require crew to record or submit the speeds/distances.

The Saab 2000 QRH includes landing distance correction factors for flaps 20 and 35 that "show the increase/ decrease in demonstrated (unfactored) landing distance from various environmental conditions" including tailwind, headwind, runway slope, wet runway, very low friction runway, and runways covered by water, slush, wet snow, dry

[6] The APG landing performance tables are constructed from factored AFM data and are intended to be consistent with FAA flight dispatch requirements. The performance binder contains Saab 2000 QRH unfactored landing distance data. This study did not determine if the referenced PenAir performance data (PenAir performance binder and APG data) are different, in part or in entirety, from the Saab 2000 AFM.

snow, or compact snow. See Table 4 for an excerpt of the available Saab 2000 landing distance correction factors. Per the Saab 2000 QRH, for combinations of environmental conditions, applicable factors are multiplied. For example, if landing at flaps 20, 10-knot tailwind, 2 percent downhill slope, wet runway, the uncorrected, demonstrated landing distance is increased by a factor of 1.21 x 1.08 x 1.15 = 1.50.

The Table 4 distance correction factors were available to PenAir flight crews to support operational (time of arrival) landing distance assessments but it is not known if the flight crew consulted these data as part of their arrival assessment. Per FAA SAFO 19001, an operational landing distance assessment (OLD) for the preceding example would incorporate an additional factor of 1.15 to yield a total factor applied to the uncorrected, demonstrated landing distance of 1.21 x 1.08 x 1.15 x 1.15 = 1.73. This example does not incorporate specific air or transition distance adjustments to account for differences between flight test and operational landing techniques. The OLD as described in FAA SAFO 19001 cannot generally be obtained by simply adding a 15 percent margin to uncorrected, demonstrated landing distance.

		FLAPS 20			FLAPS 35		
TAILWIND (Not applicable to very Low Friction Rwy)		– 5	kt	= 1.10	– 5	kt	= 1.10
		–10	kt	= 1.21	–10	kt	= 1.21
HEADWIND		+ 5	kt	= 0.98	+ 5	kt	= 0.97
		+ 10	kt	= 0.96	+ 10	kt	= 0.94
		+ 15	kt	= 0.94	+ 15	kt	= 0.91
		+ 20	kt	= 0.92	+ 20	kt	= 0.89
		+ 25	kt	= 0.9	+ 25	kt	= 0.86
		+ 30	kt	= 0.88	+ 30	kt	= 0.83
SLOPE	Downhill	–1	%	= 1.04	–1	%	= 1.03
	Downhill	–2	%	= 1.08	–2	%	= 1.06
	Uphill	+1	%	= 0.98	+1	%	= 0.98
	Uphill	+2	%	= 0.96	+2	%	= 0.96
WET RWY				= 1.15			= 1.15
WATER COVERED RWY		3 – 5	mm	= 1.60	3 – 5	mm	= 1.57
		6 – 8	mm	= 1.55	6 – 8	mm	= 1.52
		9 – 18	mm	= 1.48	9 – 18	mm	= 1.48
SLUSH COVERED RWY		3 – 5	mm	= 1.59	3 – 5	mm	= 1.57
		6 – 9	mm	= 1.54	6 – 9	mm	= 1.52
		10 – 18	mm	= 1.46	10 – 18	mm	= 1.47
WET SNOW COVERED RWY		6 – 9	mm	= 1.54	6 – 9	mm	= 1.54
		10 – 19	mm	= 1.50	10 – 19	mm	= 1.50
		20 – 26	mm	= 1.44	20 – 26	mm	= 1.44
DRY SNOW COVERED RWY		5 – 14	mm	= 1.56	5 – 14	mm	= 1.56
		15 – 30	mm	= 1.50	15 – 30	mm	= 1.50
		31 – 45	mm	= 1.46	31 – 45	mm	= 1.46
COMPACT SNOW COVERED RWY				= 1.35			= 1.33
VERY LOW FRICTION RWY				= 2.16			= 2.14

For combination of environmental conditions multiply applicable factors.

Table 4: Saab 2000 QRH landing distance correction factors

2.8.4 Saab 2000 Anti-skid Inoperative Performance Adjustment

The Saab 2000 AFM excerpt below documents limitations and recommendations for operations with the anti-skid system inoperative. For anti-skid system inoperative, the expected unfactored landing distance required will be increased by a factor of 2.2. According to Saab engineering staff, this factor assumes zero wheel braking (no brake application) above 30 knots. N686PA was dispatched for flight 3296 assuming the anti-skid system was fully operative. No N686PA anti-skid or wheel brake system issues were communicated to or from the flight crew at the time of flight dispatch or during flight 3296 prior to touchdown.

Take–off and landing with the anti–skid system inoperative will adversely effect the accelerate–stop distance and landing distance respectively, as the maximum speed for the use of maximum wheel braking is 0 knots.

Use normal take–off procedures, but apply a factor of 1/2.2 to the accelerate–stop distance available before entering dry or wet runway "Accelerate–Stop Distance" charts.

Although reverse thrust was not considered when calculating this distance factor, it's use is recommended.

When considering landing performance, the landing distance required will be increased by a factor of 2.2.

Although wheel braking was not considered when calculating these distance factors, it is recommended that gentle wheel braking is used from 30 knots.

Note that significant braking may lock the main landing gear wheels with a possible tire failure resulting.

The PenAir CFM, section 26.10.2.2 Operation with Anti-Skid Inoperative, dated 02/01/16, page 10-16, rev. original states, "Dispatch with the anti-skid system inoperative (in accordance with a special flight permit) may be performed provided the following procedures are followed." Section 26.10.2.2.2 Landing with Anti-Skid System Inoperative states, "For landing with anti-skid system inoperative a landing distance factor of 2.2 shall be applied."

2.8.5 Engine Power Lever Angle (PLA) Definitions

The Saab 2000 engine PLA positions are defined by flight regime in the AOM, Section 13/1, page 23, dated October 01/17, as depicted in Figure 6. The engine PLA positions during flight operations vary from 35° for Flight Idle (FI) to Maximum Cruise (Max. CRZ) to Maximum Climb (Max. CLB) to Maximum Continuous Power (MCP) to 80° for Normal Takeoff Power (NTOP) to 85° for Maximum Takeoff Power (MTOP). The engine PLA positions during ground operations vary from 35° for FI to 33° for Beta to 16° for Ground Idle (GI) Reverse (Rev.) to 0° for Maximum Reverse (Max. Rev.).

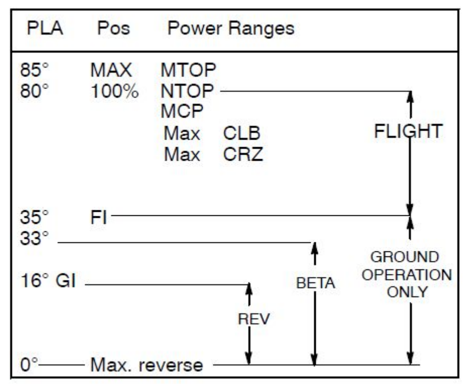

Figure 6: Definition of engine PLA positions

2.8.6 Saab 2000 Normal and Non-Normal Unfactored Landing Distance

The actual N686PA transition and rollout distances exceeded the expected stopping performance margin for a dry, grooved runway with no reverse thrust credit. One hypothesis for this outcome is that the flight crew did not apply wheel brakes shortly after MLG touchdown or maintain significant wheel braking on the improved pavement surfaces. This explanation conflicts with flight crew witness statements and available CVR, FDR, and runway witness mark evidence. An alternative hypothesis is that N686PA achieved less equivalent wheel brake retarding force at the wheel/pavement interface than expected, for reasons to be determined by this or other NTSB investigative groups.

In response to an NTSB request in December 2019, Saab engineering staff calculated unfactored transition and rollout distances for 15 Saab 2000 deceleration device configurations, including normal and non-normal landing configurations. Non-normal landings included the following Saab 2000 airplane configurations:

1. One engine inoperative
2. One or two anti-skid control circuits inoperative
3. AFR inoperative
4. Wheel brakes not applied

Additional landing performance variables included use of GI or Max Rev engine thrust on the operative engine(s). The initial conditions for the calculated landing scenarios were based on N686PA data from the accident event. The landing weight and ground speed values were purposefully selected to be conservative.

Saab engineering staff also provided a subset of Saab 2000 aerodynamics and engine model data to the NTSB aircraft performance group chairman to support a request to develop an independent, simplified Saab 2000 landing performance model. The NTSB simplified landing performance model results are compared to the Saab results for the first 15 normal and non-normal landing distance scenarios in Table 5. The calculated NTSB landing distances generally agree well with the reference Saab values for all 15 scenarios. The NTSB simplified model generates landing distances up to 1 percent longer or up to 5 percent shorter than the corresponding Saab model. The air distance and transition distance values were fixed in both the Saab and the NTSB models.

The Table 5 results indicate that N686PA should have had adequate performance capability to stop within the runway 13 LDA for all cases when both anti-skid control circuits were operative (cases 1, 4, 7, 10, and 13) and with one anti-skid control circuit inoperative and all engines operating (AEO) at Max Rev (case 8). In addition, N686PA should have been able to stop on the improved pavement surface near the RSA/blast pad transition point with one anti-skid circuit inoperative and AEO at GI thrust (cases 2 and 5).

After a group discussion of the Flaps 20 results for cases 1–15, Flaps 35 performance was added to Table 5 for 4 wheel brake configurations to expand visibility to the Saab 2000 landing performance capabilities. Scenarios 7–9 were modified from flaps 20 to flaps 35 to construct scenarios 17–19, which complement the landing distance scenarios presented in Table 3. The initial conditions for all flaps 35 scenarios are identical to the flaps 20 initial conditions except that airspeed has been adjusted for the lower VREF and touchdown speeds for flaps 35. The same speed increment added in the form of a tailwind for flaps 20 cases 1–15 was added to the nominal VREF for flaps 35. Similarly, cases 16 and 20 were added for flaps 20 and 35, respectively, to estimate the average braked wheel/pavement friction required to match the FDR-based N686PA deceleration.

The calculated aircraft average deceleration for each case is shown in the last two columns of Table 5 for comparison to flight test data and N686PA data. The average aircraft deceleration value during the transition and rollout segments is shown in the second to the last column. The last column presents the average aircraft deceleration value during the rollout segment (i.e., all deceleration devices fully applied/configured). With two anti-skid circuits active, the average aircraft deceleration rate at flaps 20 (which becomes flaps 15 due to AFR after MLG touchdown) is expected to vary between about 7 and 9 knots per second during the transition and rollout segments for all engine thrust settings evaluated. The Case 16 average deceleration rate required to match the documented N686PA stopping performance was about 5 knots per second.

The flaps 35 average deceleration results for cases 17–19 are quite similar to the flaps 20 average deceleration results for cases 7–9. However, the calculated flaps 35 stopping distances are several hundred feet shorter than the comparable flaps 20 cases, as expected.

For the flaps 20 cases with two anti-skid circuits inactive (and no wheel braking above 30 knots), the calculated performance increment from AEO FI to AEO Max Rev is about the same order of magnitude as the increments from OEI Max Rev to OEI FI or from AEO Max Rev to OEI Max Rev. Data from the wheel brakes not applied scenarios were used to isolate the engine thrust effects on the calculated transition and rollout distances. Observations from the flaps 20 results in Table 5 include:

1. The transition and rollout distance for OEI FI exceeds the comparable distance for AEO FI
2. The transition and rollout distance for OEI Max Rev exceeds the comparable distance for AEO FI
3. The effect of AEO Max Rev is approximately the same as the effect of OEI Max Rev

These engine thrust observations do not necessarily generalize for comparable turbofan engine operations.

Initial Conditions

weight	46,000 pounds	(conservative, N686PA = 45,213 pounds, 142 knots ground speed, flaps 20)
c.g.	34.8 %MAC	based on load manifest
altimeter	29.50 in. Hg	
temperature	8 °C	ISA -6.9°C at 22 ft field level

Case	Landing Description	Flaps	Airspeed knots	Ground Speed knots	AFR	Wheel Brakes	Anti-Skid Circuits Active	Engines Operable	Engine Thrust	Runway Surface	(A) Air Distance feet	(T) Transition Distance feet	(R0) Rollout Distance feet	(A + T + R0) Stopping Distance feet	Simplified NTSB Model (A + T + R0) Stopping Distance feet	NTSB Stopping Distance Error Relative to Saab Model percent	(T + R0) Calculated Airplane Average Decel. knots/sec	(R0) Calculated Airplane Average Decel. knots/sec	Note
1	Normal	20	127	143	active	applied	2	2	GI	bare & dry	1100	425	1701	3226	3118	-3.4	8.1	9.0	a
2	Non-Normal	20	127	143	active	applied	1	2	GI	bare & dry	1100	425	2673	4198	4140	-1.4	5.6	5.7	
3	Non-Normal	20	127	143	active	not applied	0	2	GI	bare & dry	1100	425	5653	7178	7214	0.5	2.8	2.7	
4	Non-Normal	20	127	143	inactive	applied	2	2	GI	bare & dry	1100	425	1713	3238	3118	-3.7	8.1	9.0	b
5	Non-Normal	20	127	143	inactive	applied	1	2	GI	bare & dry	1100	425	2686	4211	4140	-1.7	5.5	5.7	
6	Non-Normal	20	127	143	inactive	not applied	0	2	GI	bare & dry	1100	425	5663	7188	7214	0.4	2.8	2.7	
7	Non-Normal	20	127	143	active	applied	2	2	Max Rev	bare & dry	1100	425	1523	3048	2980	-2.2	8.9	10.1	
8	Non-Normal	20	127	143	active	applied	1	2	Max Rev	bare & dry	1100	425	2253	3778	3762	-0.4	6.4	6.8	
9	Non-Normal	20	127	143	active	not applied	0	2	Max Rev	bare & dry	1100	425	3773	5298	5340	0.8	4.1	4.1	
10	Non-Normal	20	127	143	active	applied	2	1	Max Rev	bare & dry	1100	425	1875	3400	3255	-4.3	7.5	8.2	a
11	Non-Normal	20	127	143	active	applied	1	1	Max Rev	bare & dry	1100	425	2976	4501	4431	-1.6	5.1	5.2	
12	Non-Normal	20	127	143	active	not applied	0	1	Max Rev	bare & dry	1100	425	5938	7463	7521	0.8	2.7	2.6	
13	AFM Landing	20	127	143	active	applied	2	1	GI	bare & dry	1100	425	1995	3520	3344	-5.0	7.1	7.7	a
14	Non-Normal	20	127	143	active	applied	1	1	GI	bare & dry	1100	425	3285	4810	4705	-2.2	4.7	4.7	
15	Non-Normal	20	127	143	active	not applied	0	1	GI	bare & dry	1100	425	7788	9313	9260	-0.6	2.1	2.0	
16	Non-Normal	20	127	143	active	applied	0-1	2	Max Rev	bare & dry	1100	425	2957	4482	---	---	5.1	5.2	c
17	Non-Normal	35	116	131	active	applied	2	2	Max Rev	bare & dry	1100	384	1337	2821	---	---	8.4	9.8	d
18	Non-Normal	35	116	131	active	applied	1	2	Max Rev	bare & dry	1100	384	2000	3484	---	---	6.1	6.6	d
19	Non-Normal	35	116	131	active	not applied	0	2	Max Rev	bare & dry	1100	384	3332	4816	---	---	3.9	3.9	d
20	Non-Normal	35	116	131	active	applied	0-1	2	Max Rev	bare & dry	1100	385	2587	4072	---	---	4.9	5.1	d

Notes: Non-Normal configurations are highlighted in red

a) Flight test performed and contributes to a common AFM data set
b) The effect of AFR was based on flight test with 1-engine reverse
c) Adjusted to match FDR deceleration (resulting brake μ ~ 30%)
d) Cases 17, 18, 19, and 20 at flaps 35 included for comparison to cases 7, 8, 9, and 16 at flaps 20

Transition distance (T) calculated using nominal AFM data constant
Flaps 20: 1.81 seconds transition time, 8.1 knots transition speed loss
Flaps 35: 1.81 seconds transition time, 6.2 knots transition speed loss

Anti-skid circuit modeling
1 Active, 50% dry brake μ
0 Active, 0.05 brake μ (rolling wheel) above 30 knots ground speed, normal dry μ below 30 knots

Table 5: Calculated Saab 2000 normal and non-normal, unfactored landing distance (comparison of Saab and NTSB simplified landing performance models) and airplane constant deceleration during transition and roll out

2.8.7 Saab 2000 Flight Test Data

In late February 2020, the NTSB aircraft performance group convened at a Saab engineering facility in Linköping, Sweden to discuss Saab 2000 flight dispatch calculations, normal landing distance calculations, non-normal landing distance calculations, operational (time of arrival) landing distance assessments, N686PA flight data recorder data, and flight test conditions and data pertinent to the N686PA landing overrun investigation. The two-day meeting was attended by subject matter experts from SHK, Saab, PenAir, FAA, and NTSB.

Prior to the meeting, Saab engineering staff were requested to identify applicable company or certification Saab 2000 landing and rejected takeoff flight test conditions, including normal and non-normal configuration landing and rejected takeoff conditions. The following parameters were reviewed for each flight test condition—airplane weight and center of gravity position; flight path angle, for landings; landing reference speed (VREF) or takeoff decision speed (V1), as applicable; airspeed at runway threshold crossing or rejected takeoff first action; ground speed at main gear touchdown or rejected takeoff first action; flap position and whether or not the automatic flap retraction system retracted flaps to flaps 15; number of operative engines and/or feathered propellers; the engine/propeller thrust setting and duration for each engine (e.g., two engines in reverse at nose wheel touchdown, specified engine PLA, propeller rpm and blade angle commanded, and airspeed at which engines/ props were returned to ground idle or forward idle setting); wheel brake setting and duration (e.g., maximum manual braking commanded at nose wheel touchdown, maintained until aircraft came to a complete stop); anti-skid system operative status (i.e., either two circuits operative, only inboard circuit operative, only outboard circuit operative, neither circuit operative, or other, such as wheel brakes and anti-skid system fully operative but purposefully not applied); whether or not the flight test condition was used to support the aircraft certification; and, if applicable, a description of any additional non-normal aircraft configuration conditions.

Saab engineering staff were also asked to provide the NTSB with the Saab 2000 parametric air distance equation; the reference point for each deceleration device action; the time schedule, setting, duration, and stow/release point/criteria for each deceleration device action, and aerodynamics and engine data for flaps 20 and 15 for the airplane at the nominal ground roll attitude. These data are considered business proprietary and are not available for public release.

The flight test nomenclature used in this section includes All Engines Operating (AEO), One Engine Inoperative (OEI), Flight Idle (FI) thrust, Ground Idle (GI) thrust, and V_FB, the ground speed at which full commanded brake pressure is achieved.

Saab engineers provided visibility to existing Saab 2000 flight test data for accelerate-stop, normal landing, touch and go, and rejected takeoff test conditions that were flown to support Saab 2000 development and certification efforts. The company tests evaluated various Saab 2000 performance capabilities for airplane weights ranging from 40,000 to 52,000 pounds; forward to midrange center of gravity positions; flaps 0, 15, 20, or 35; AEO or OEI; thrust settings of ground idle (GI), flight idle (FI), climb (CLB), takeoff/go-around (TOGA), or maximum reverse (Max Rev); airplane configured with or without automatic flap retraction (AFR) for landing cases; and maximum manual braking (Max), if wheel braking was applied.

Saab 2000 time history data from 12 flight test conditions were reviewed by the NTSB aircraft performance group.[7] The respective flight test purpose, airplane loading, airplane flap, engines operating, thrust setting, and wheel brake configuration are summarized in Table 6. Cases 1–8 and 11–12 are representative of the Saab 2000 deceleration capability on a dry runway as a function of airplane loading, configuration, and deceleration device configuration. Cases 9 and 10 were touch and go test conditions that were excluded. The flight test parametric data for each case included plots of airplane groundspeed as a function of time. The slope of this line, delta

[7] Airplane manufacturer flight test data, wind tunnel test data, and engineering models and data (including computational fluid dynamics, structures, aeroelastics, aerodynamics, engine, control system, avionics, and integrated aircraft simulation models) are considered business proprietary and therefore are not disseminated to all investigative parties or publicly released.

groundspeed (dV) divided by delta time (dT), yields the demonstrated Saab 2000 average deceleration (on a dry runway) over time interval dT.

The calculated deceleration value for each flight test case from transition through rollout and complete stop is presented in the far right column of Table 6. The empirical results indicate that a fully functional Saab 2000 can generate average deceleration rates ranging from 6 to 9 knots per second with maximum wheel braking and operable anti-skid system. The 3-knot per second variation among cases is a function of the landing flap, number of operating engines, engine thrust setting, and automatic flap retraction configuration. These Saab 2000 data justify using a conservative average deceleration value of 6 knots per second to evaluate the N686PA energy dissipation capability during landing roll out. N686PA was configured flaps 20, AFR active, AEO, Max Rev, Max brakes.

Table 6: Saab 2000 flight test conditions related to stopping performance

Case	Description	Weight lb	CG %	Flap	Engine	Thrust	AFR	Brakes	dV knots	dT seconds	dV/dT knots/sec
1	Accel-Stop	40486	13.36	0	AEO	GI	No	Max	128	14.3	9.0
2	Accel-Stop	39877	13.02	0	OEI	GI	No	Max	107	14	7.6
3	Accel-Stop	39966	13.07	20	OEI	GI	No	Max	114	15.5	7.4
4	Accel-Stop	40762	13.52	20	OEI	Max Rev	No	Max	93	11.8	7.9
5	Accel-Stop	39833	13.00	35	OEI	GI	No	Max	49	8	6.1
6	Landing	49553	20.19	35	OEI	Max Rev	No	Max	111	15.8	7.0
7	Landing	49299	20.08	35	OEI	Max Rev	Yes	Max	110	14	7.9
8	Landing	48420	20.06	35	OEI	GI	Yes	Max	114	14.5	7.9
11	RTO	52012	23.70	0	AEO	FI	No	Max	160	23.5	6.8
12	Accel-Stop	45727	20.65	15	AEO	GI	No	Max	---	---	---

2.9 Constant Acceleration Model

N686PA main gear touchdown occurred at 142 knots groundspeed, about 1,100 feet beyond the runway 13 displaced threshold. Given the LDA of 3,900 feet and an air distance of 1,100 feet, there was 3,900 – 1,100 = 2,800 feet of runway stopping distance remaining. The constant acceleration equations for position X(t) and speed V(t), where X_0 is the initial position, V_0 is the initial speed, t is time, and a_x is the acceleration, are

$$X(t) = X_0 + V_0*t + ½*a_x*t^2 \quad (1a)$$

$$V(t) = V_0 + a_x*t \quad (2a)$$

Rearranging terms gives

$$X(t) - X_0 = V_0*t + ½*a_x*t^2 \quad (1b)$$

$$V(t) - V_0 = a_x*t \quad (2b)$$

Equation 2b is then used to substitute for a_x*t in equation 1b and solve for time, t

$$X(t) - X_0 = t*\{ V_0 + ½*[V(t) - V_0] \} \quad (3a)$$

$$X(t) - X_0 = t*\{ ½*[V_0 + V(t)] \} \quad (3b)$$

$$t = 2*[X(t) - X_0] / [V_0 + V(t)] \quad (4)$$

Inserting numeric values for N686PA into equation 4 and accounting for consistent units gives

$$t = 2*[2800 - 0] / \{ [142 + 0]*6076.115/3600 \}$$

$$t = 23.37 \text{ sec}$$

That is, the maximum time available to stop on runway 13 if N686PA decelerates at the minimum constant deceleration rate is 23.37 seconds. Equation 2b is solved for acceleration, a_x and numeric values for N686PA are inserted to calculate the corresponding acceleration in knots per second as follows

$$a_x = [V(t) - V_0] / t \qquad (5)$$

$$a_x = [0 - 142] / 23.37$$

$$a_x = -6.1 \text{ knots/second}$$

The minimum constant deceleration that will allow N686PA to stop within the remaining runway distance of 2,800 feet is 6.1 knots/second. Alternatively, equation 4 can be substituted into equation 2b, simplified, and solved for acceleration, a_x

$$a_x = \{ [V(t) - V_0] [V_0 + V(t)] \} / \{ 2*[X(t) - X_0] \} \qquad (6a)$$

$$a_x = \{ V(t)^2 - (V_0)^2 \} / \{ 2*[X(t) - X_0] \} \qquad (6b)$$

Equation 6b is solved for acceleration, a_x in knots per second by inserting numeric values for N686PA to give

$$a_x = \{ [(0)^2 - (142)^2]*6076.115/3600 \} / \{ 2*[2800 - 0] \}$$

$$a_x = -6.1 \text{ knots/second}$$

Equation 6b was used to compute the N686PA deceleration required to stop within the runway 13 LDA as a function of hypothetical delay times, ranging from 0 to 4 seconds, for the flight crew to accomplish maximum wheel brake application. The airplane distance traveled during the hypothetical delay time is based on a conservative, constant ground speed of 142 knots. The resulting range of constant deceleration values shown in Table 7 is consistent with the range of flight test demonstrated Saab 2000 deceleration rates in Table 6.

Table 7: N686PA deceleration required to stop within runway 13 LDA

Hypothetical time delay to maximum brake application, seconds	N686PA position relative to TD at maximum brake application, X_0 feet	Deceleration required to stop in runway 13 LDA, knots/second	Time required to stop in runway 13 LDA, seconds	Comment
0	+0	6.1	0 + 23.37	No time delay
1	+240	6.7	1 + 21.37	1 sec. delay at 142 kts
2	+480	7.4	2 + 19.36	2 sec. delay at 142 kts
3	+720	8.2	3 + 17.36	3 sec. delay at 142 kts
4	+960	9.3	4 + 15.36	4 sec. delay at 142 kts

Compared to flight test cases 7 and 8 in Table 6, N686PA should have had the deceleration capability needed to stop in the runway 13 LDA for the following reasons:

1. N686PA had high main gear loading due to the aft center of gravity required to meet the alternate forward CG II dispatch criteria
2. The N686PA landing rollout also occurred at flaps 15 main gear loading due to AFR from flaps 20 to 15, per the flight data recorder
3. The N686PA landing weight was about 4,000 pounds less than case 7 and about 3,000 pounds less than case 8
4. N686PA used AEO at ground idle (GI) and then maximum reverse (Max Rev) as opposed to OEI with the remaining engine at Max Rev thrust for case 7, and OEI with the remaining engine at GI thrust for case 8

5. The demonstrated deceleration rates in cases 7 and 8 were 7.9 knots per second, at or above the Table 7 minimum required deceleration rate for hypothetical wheel brake application delays as long as 2.5 seconds.

Equation 6b was also used to compute the N686PA deceleration required to stop within the runway 13 LDA plus RSA plus blast pad (BP) distance, which equals 3,900 – 1,100 + 300 + 140 = 3,240 feet. As before, the calculations consider hypothetical delay times ranging from 0 to 4 seconds for the flight crew to accomplish maximum wheel brake application and the airplane is assumed to progress down the runway at a constant ground speed of 142 knots during the applicable delay period. The corresponding constant deceleration values in Table 8 decreased from 0.8 to 1.8 knots per second relative to the Table 7 values. As expected, allowing the airplane to use the added RSA and blast pad distance for emergency stopping margin lowers the average deceleration rate required to dissipate the airplane energy. All of the cases in Table 8 demonstrate that N686PA should have had the performance capability to stop within the LDA + RSA + blast pad distance.

Table 8: N686PA deceleration required to stop within runway 13 LDA + RSA + blast pad

Hypothetical time delay to maximum brake application, seconds	N686PA position relative to TD at maximum brake application, X_0 feet	Deceleration required to stop in runway 13 LDA + RSA + BP, knots/second	Time required to stop in runway 13 LDA + RSA + BP, seconds	Comment
0	+0	5.3	0 + 27.04	No time delay
1	+240	5.7	1 + 25.04	1 sec. delay at 142 kts
2	+480	6.2	2 + 23.04	2 sec. delay at 142 kts
3	+720	6.8	3 + 21.03	3 sec. delay at 142 kts
4	+960	7.5	4 + 19.03	4 sec. delay at 142 kts

Finally, equation 6b was used to estimate the constant deceleration required to match the N686PA ground speed of about 29 knots as it departed the improved pavement surface after overrunning the runway 13 LDA, 300-foot RSA, and 140-foot blast pad. The same assumptions apply for hypothetical delay times (0 to 4 seconds for the flight crew to accomplish maximum wheel brake application) and ground speed (constant at 142 knots prior to wheel brake application). The calculated constant deceleration values in Table 9 are all biased downward by about 0.3 knots per second relative to the corresponding Table 8 scenarios.

Table 9: N686PA deceleration required to slow to 29 knots within runway 13 LDA + RSA + blast pad

Hypothetical time delay to maximum brake application, seconds	N686PA position relative to TD at maximum brake application, X_0 feet	Deceleration required to slow to 29 knots in runway 13 LDA + RSA + BP, knots/second	Time required to slow to 29 knots in runway 13 LDA + RSA + BP, seconds	Comment
0	+0	5.0	0 + 22.45	No time delay
1	+240	5.4	1 + 20.79	1 sec. delay at 142 kts
2	+480	5.9	2 + 19.13	2 sec. delay at 142 kts
3	+720	6.5	3 + 17.46	3 sec. delay at 142 kts
4	+960	7.2	4 + 15.80	4 sec. delay at 142 kts

The deceleration results in Table 9 are generally substantially below (or, as the hypothetical time delay to maximum brake applications increases, artificially biased upward, toward) the lowest deceleration rates demonstrated by Saab during the Saab 2000 flight test development and certification efforts. If the N686PA flight crew commanded and maintained maximum manual wheel braking (to allow the anti-skid system to modulate the main gear wheel brakes as needed to prevent a wheel skid on the inboard and/or outboard anti-skid control circuit), the significant differences between the demonstrated Saab 2000 deceleration capability in Table 6 and the estimated N686PA deceleration capability in Table 9 indicate that the accident airplane stopping capability during the landing rollout was degraded. Moreover, a degraded N686PA stopping performance capability was likely due to the wheel brake, anti-skid, and/or wheel/tire system because

1) The runway 13 surface condition evidence shows that the pavement was dry, grooved, and in good repair
2) The N686PA aerodynamic drag configuration after flap retraction from 20 to 15 matched the flight test configuration for cases 7 and 8 in Table 6
3) The N686PA main gear loading due to AFR matched the flight test configuration for cases 7 and 8 in Table 6
4) The N686PA main gear loading was substantially further aft than the flight test configuration for cases 7 and 8 in Table 6
5) The N686PA landing weight was 3,000 to 4,000 pounds lighter than the flight test configuration for cases 7 and 8 in Table 6
6) The N686PA engine/propeller configuration of AEO at GI thrust transitioning to maintained Max Rev thrust exceeded the corresponding flight test engine/propeller contributions to airplane energy dissipation

For comparison purposes, the cockpit voice recorder (CVR) evidence indicates that 25.1 seconds elapsed between airplane touchdown and airplane departure from an improved surface. The FDR data indicate touchdown occurred at 142 knots ground speed and blast pad departure occurred 24.2 seconds later at 29 knots ground speed. The FDR-based average deceleration was $dV/dT = -(29 - 142)/24.2 = 4.7$ knots per second. The CVR elapsed time is 0.9 seconds longer than the FDR-based elapsed time between main gear touchdown and airplane departure from the improved surface. The CVR-based average deceleration was $dV/dT = -(29 - 142)/25.1 = 4.5$ knots per second.

The magnitudes of the average deceleration values in Table 9 are likely higher than the N686PA FDR- and CVR-based average deceleration values because the actual airplane groundspeed was less than the 142-knot value assumed in the Table 9 cases (to account for various hypothetical delay times for the flight crew to accomplish maximum manual wheel braking).

2.10 Airplane Braking Coefficient Extraction

The NTSB simplified aerodynamics and engine models for the Saab 2000 were used to calculate the expected airplane braking coefficient as a function of time during the N686PA landing rollout. The calculation began at nose gear touchdown and continued until the aircraft left the improved pavement surface. The measured and calculated values of airplane ground speed in knots and airplane acceleration in knots per second are plotted in Figure 7. Calculated acceleration values initially increase to about 7 knots per second within 4 seconds of main gear touchdown but then steadily decrease and remain less than 6 knots per second for an 18-second period. The N686PA calculated airplane braking coefficient results are shown in Figure 8. Each plot is annotated with engine thrust, nose wheel touchdown, runway witness mark, and passenger video evidence.

Note that the friction coefficient available at the wheel/pavement interface is dependent on environmental conditions (temperature, precipitation, contaminant type and depth), pavement conditions (material, grooving, installation quality, macrotexture, microtexture, drainage capability, rubber deposits, painted surfaces, state of repair), and wheel conditions (tire inflation pressure, tread depth, tread pattern). The available friction coefficient is allocated between traction (for longitudinal braking or acceleration effort) and steering or cornering, as conditions permit for the vehicle maneuvering requested.

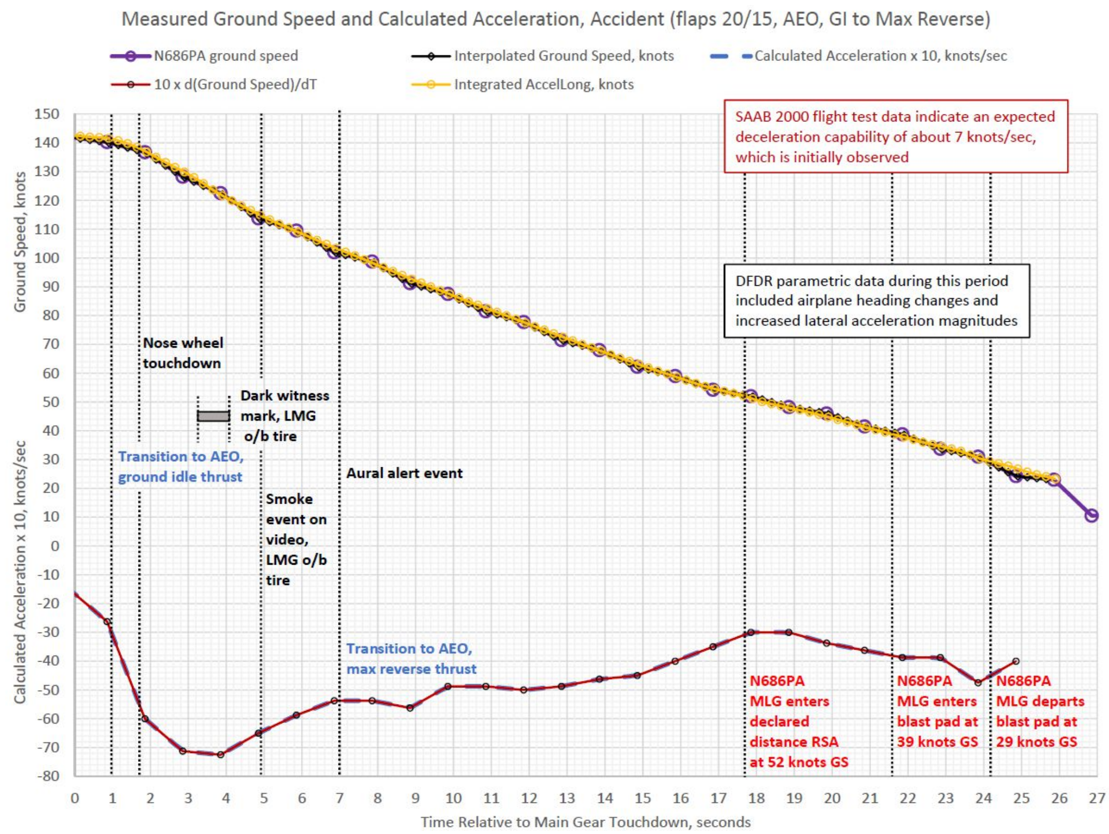

Figure 7: N686PA measured ground speed and calculated acceleration (divide latter value by 10 for actual)

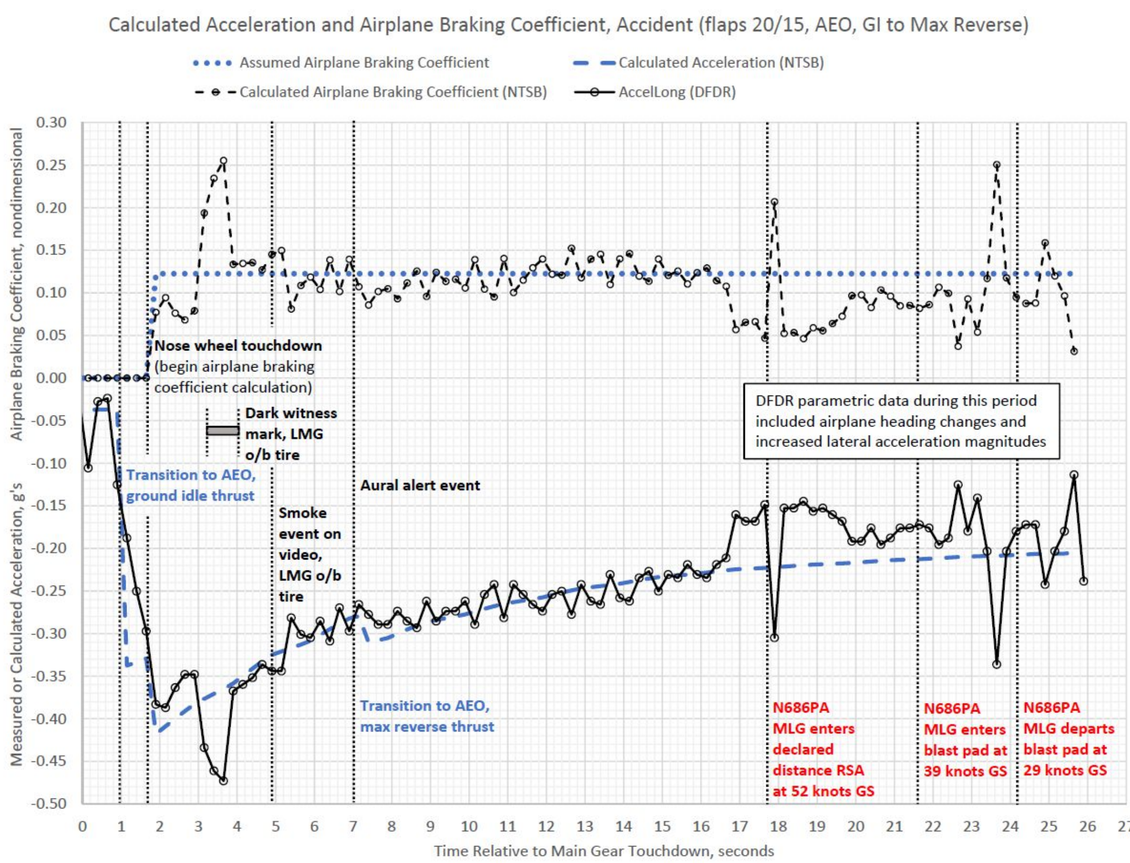

Figure 8: N686PA calculated acceleration and airplane braking coefficient (NTSB simplified Saab 2000 model)

The airplane braking coefficient is calculated using a force and moment balance (or energy conservation) approach to model the aircraft landing as a function of time; account for recorded airplane acceleration parameters; calculate the forces and moments due to aerodynamic lift, aerodynamic drag, engine thrust, aircraft loading, and runway slope; and solve for the resultant retarding force and braking coefficient at the wheel/runway interface at each time step.

For conceptual reference, the airplane braking coefficient values expected for maximum manual wheel braking with an operative anti-skid system are about 0.40 or above for bare and dry pavement, 0.20 for good braking action, 0.10 for medium (fair) braking action, and 0.05 for poor braking action.

The N686PA calculated airplane braking coefficient in Figure 8 is highest (about 0.26) in the time window that corresponds to the long, dark witness mark associated with the left main gear outboard tire. The average airplane braking coefficient value during the rollout period when the airplane is within the runway 13 LDA is about 0.12. About one second before the airplane enters the runway 13 RSA, the magnitude of the recorded longitudinal acceleration substantially decreases, which is directly reflected in reduced airplane braking coefficient values (varying between about 0.05 and 0.10). This transition could be explained, for example, by a combination of wheel braking requests and tire braking and/or cornering demands due to purposeful directional control inputs.

Proper interpretation of extracted airplane braking coefficient values is generally dependent on corroborating factual evidence. For example, without specific reference to the N686PA accident flight, hypothetical airplane braking coefficient values in the neighborhood of 0.10 could be explained by purposefully light wheel braking requested by the flight crew; poor runway pavement macrotexture or microtexture; heavy paint markings or rubber deposits on the runway; poor wheel/tire maintenance condition; the presence of significant runway surface contamination (typically due to some form of precipitation), a problem with the wheel brake or anti-skid system; errors or limitations in the underlying aerodynamics or engine models; or improper configuration/ application of the aircraft models, engine models, and/or event environmental conditions relative to the event aircraft.

The N686PA FDR contains no record of the captain’s or first officer’s commanded brake pedal position, brake pressure upstream of the anti-skid valves, brake pressure downstream of the anti-skid valves, or individual main gear wheel speeds. Therefore, direct FDR time history evidence of flight crew maximum manual wheel braking requests, purposeful or inadvertent partial wheel brake requests, intentional or inadvertent left or right wheel braking requests for directional control, and purposeful partial or full brake release is unavailable to the investigation. Similarly, there is no direct FDR time history record of the anti-skid system command(s) to apply or release the brakes on the inboard wheel(s) and/or the outboard wheel(s).

2.11 Flight Crew Witness Statements Regarding Wheel Brakes and Runway 13 Surface Conditions

No FDR parametric data document MLG wheel speeds, wheel brake commands, or wheel brake pressures upstream or down-stream of the anti-skid valves for the inboard circuit (left and right inboard MLG wheels) and the outboard circuit (left and right outboard MLG wheels). Excerpts of PF and PM witness statements gathered by Operations and Human Performance investigators are duplicated below (with **bolded** text added for references to wheel brakes and runway surface condition):

> **Pilot Flying:**
> “We touched down normally. For Dutch it's normally stiff. You hit your spot, it's going to be a stiff landing. Stiff, boom, you hit, put it in reverse. When the nose wheel came down, he called Beta lights. **I'm on brakes** and I'm on the steering. I called bottoms; he called tops. That's what we called that when we switch.
>
> So as we're rolling out, airplane decelerated fairly quickly to 80 knots, and then I noticed that it stopped decelerating a little bit and then I **pushed as hard as I could**. I was starting to push as I could on

the brakes, and I'm pushing -- pulling it all the way in reverse. It's slowing, but it's not slowing at the rate it normally would. And … [name redacted] … **I start recognizing as we're coming up to where we're normally slow, we're not as slow as we should be and I'm not getting a response from the brakes.**

There's no response from the brakes, end of the runway's coming up. And as we approach the end of the runway, I'm looking to see what can I turn in on."

Q. **Was the runway dry?**

A. **Completely dry or damp.** It was considered -- **they call it wet, but it's a grooved runway, which is, as performance is,** you know, **is considered dry runway. There was no puddles, visible puddles or standing water that I could see.**

Pilot Monitoring (First Officer):

"And so as soon as we touched down, I took the yoke and saw the windsock was pointing directly across the runway, and I turned right into it. And he -- and I looked at the indicators to make sure that **as soon as I saw the Betas, called Betas, and he went full reverse and was on the brakes**. And I was looking at the speed tape. I saw 80 knots, called 80 knots. And I looked up, and everything initially was looking normal.

As we were proceeding down the runway, we were coming up to where we would normally start thinking about taxiing off, and I noticed that we were faster than normal. It didn't seem excessively fast, but it definitely felt faster than normal, and I made a comment to him, **you're going to need to get on the brakes**. At that point he said, **I'm full brakes right now. And I put my feet up on the rudder pedals as well, and I pushed full brakes to verify and they didn't budge. They were full -- he had full application on the brakes**." We were continuing. I saw the inlet. The last thing I wanted to do was to go off the end of the runway into water, so I told him, go right, right, go right. And **I let off the left brake and I applied full right rudder braking action to try to drive the plane to the right**, because there was a road there that we could try to avoid going off the end.

2.12 Airplane Braking Coefficient Validation (NTSB Simplified Saab 2000 Model)

The Saab 2000 aerodynamics and engine models were used with airplane configuration and loading data to calculate the airplane braking coefficient during a flight test accelerate-stop maneuver. The results in Figure 9(a) demonstrate expected, nearly constant, rolling wheel friction coefficient values during the takeoff ground roll as well as expected airplane braking coefficient values during a maximum performance stop event (rejected takeoff, RTO) on a bare and dry runway.

The discrepancy between the assumed airplane braking coefficient on a bare and dry runway and the calculated airplane braking coefficient between elapsed times 29 to 32 seconds is due to limitations of the engine/propeller discing thrust during the dynamic transition from forward to reverse thrust. The magnitude of the engine/propeller thrust model error can be estimated by assuming the nearly constant airplane braking coefficient value calculated between times 32 to 43 seconds is available during the transition from forward to reverse thrust. The results in Figure 9(b) demonstrate the effect of applying a correction for engine/propeller disc thrust during the configuration transition from engine forward to reverse thrust.

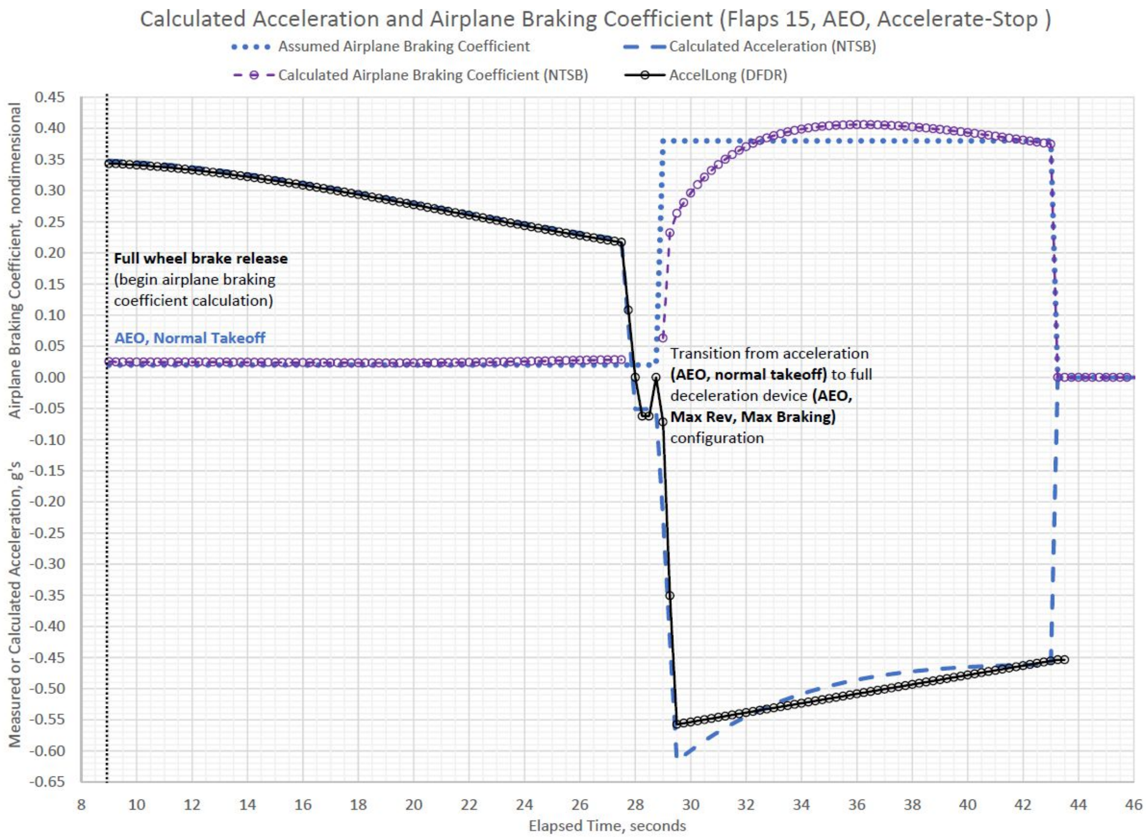

Figure 9(a): Calculated acceleration and airplane braking coefficient values for Saab 2000 accelerate-stop flight test condition (NTSB simplified Saab 2000 model, without engine reverse thrust transition correction)

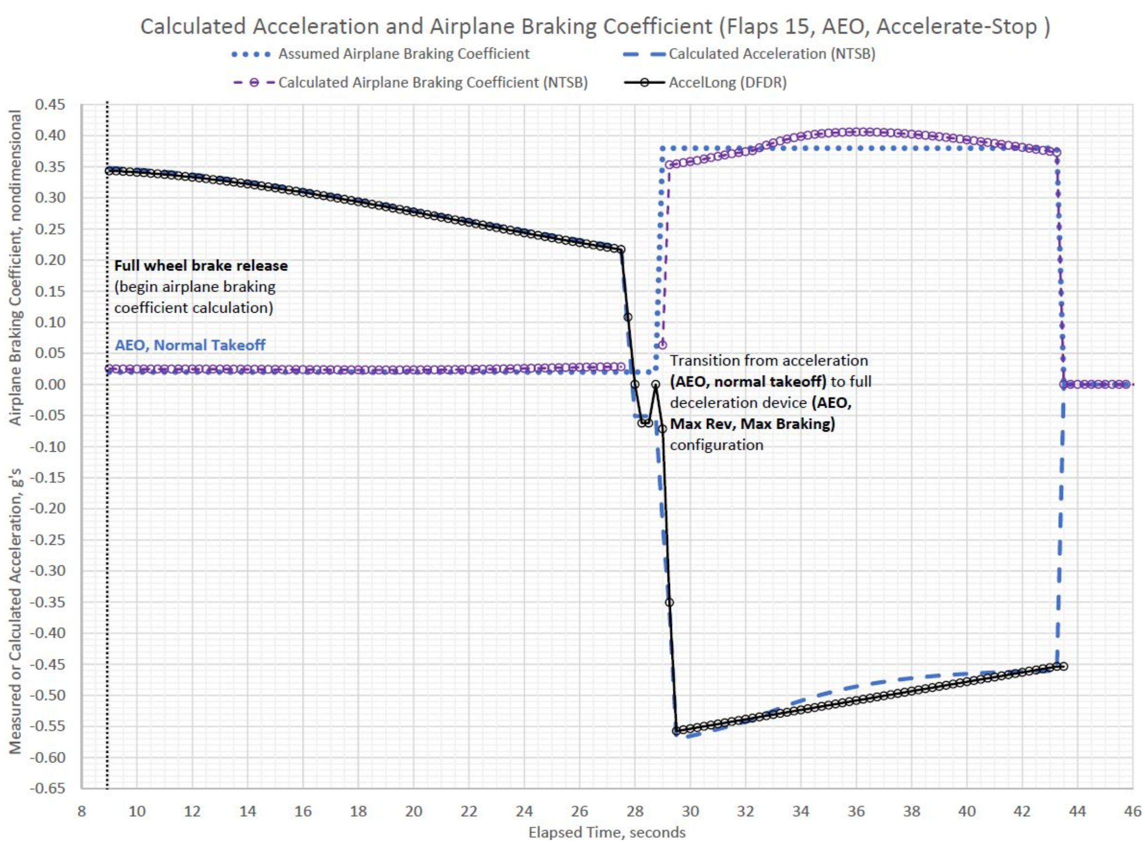

Figure 9(b): Calculated acceleration and airplane braking coefficient values for Saab 2000 accelerate-stop flight test condition (NTSB simplified Saab 2000 model, with engine reverse thrust transition correction)

2.13 Cockpit Voice Recorder (CVR) Data

The CVR EGPWS altitude callouts were aligned with the FDR radio altitude data to establish the time correlation between FDR and CVR events. The time alignment is 17:40:00 AKDT = 156969.25 FDR subframe reference number (SRN), which is equivalent to AKDT = SRN – 93,369.25.

A list of N686PA sanitized CVR events is presented in Table 10 with complementary FDR gear deployment, flap selection, MLG touchdown, and improved surface departure evidence. These data establish the time alignment necessary conditions (i.e., required event sequence) and sufficient conditions (i.e., common event occurrences, such as EGPWS radio altitude callouts, MLG touchdown, or VHF key events). Sanitized CVR events generally represent machine-generated annunciations or paraphrased flight deck, outbound, or inbound communications. The HH:MM:SS data in Table 10 correspond to Alaska Daylight Time (AKDT).

The sanitized CVR events were overlaid on the N686PA ground track to construct the runway 13 planform overview plots in Attachment 1, Figures A1.1–3. FDR ground speed and FDR anti-skid fault indication parameters were added to Figures A1.2–3 to illustrate the N686PA energy state and anti-skid fault events as a function of runway 13 longitudinal position. The sanitized CVR events shown in Figures A1.2–3 were removed to focus on the FDR ground speed and FDR anti-skid fault indication parameters in Figures A1.4–5.

Table 10: Sanitized CVR events with selected FDR reference events

HH	MM	SS	FDR SRN	Source	Sanitized CVR content or FDR event
17	9	0.75	155110.00	FDR	Top of descent
17	37	22.60	156811.85	CVR	Pilot calls for gear down
17	37	24.40	156813.65	CVR	[EGPWS] 1000 ft callout
17	37	25.36	156814.61	FDR	Gear down (time of initial travel)
17	37	25.90	156815.15	CVR	Pilot calls for flaps 15
17	37	27.53	156816.77	FDR	Flaps 15 (time of initial travel)
17	37	49.30	156838.55	CVR	Pilot calls for flaps 20
17	37	49.53	156838.77	FDR	Flaps 20 (time of initial travel)
17	38	35.80	156885.05	CVR	Dutch Weather reports winds 300 at 24
17	38	59.20	156908.45	CVR	Pilot calls mobile one to clear the crossing road and close the accompanying gates
17	39	5.40	156914.65	CVR	[EGPWS] 500 ft callout
17	39	16.30	156925.55	CVR	[EGPWS] 400 ft callout
17	39	28.30	156937.55	CVR	[EGPWS] 300 ft callout
17	39	38.40	156947.65	CVR	[EGPWS] 200 ft callout
17	39	44.00	156953.25	CVR	[EGPWS] Sink Rate callout
17	39	45.40	156954.65	CVR	[EGPWS] Sink Rate callout
17	39	46.90	156956.15	CVR	[EGPWS] 50 ft callout
17	39	48.20	156957.45	CVR	[EGPWS] 40 ft callout
17	39	48.90	156958.15	CVR	[EGPWS] 20 ft callout
17	39	50.10	156959.35	CVR	[EGPWS] 10 ft callout
17	39	53.39	156962.64	FDR	Main gear touchdown
17	39	53.40	156962.65	CVR	Sound similar to touchdown
17	39	54.30	156963.55	CVR	Sound similar to engine reverse
17	39	55.29	156964.54	FDR	Nose gear touchdown
17	40	0.00	156969.25	CVR	Pilot 80 kt callout
17	40	0.90	156970.15	CVR	Sound similar to Master Caution
17	40	5.70	156974.95	CVR	Sound similar to Master Caution
17	40	7.90	156977.15	CVR	Sound of two thuds
17	40	15.90	156985.15	CVR	Sound similar to Master Caution
17	40	18.50	156987.75	CVR	Sound of multiple low frequency thumps and thuds

The sanitized CVR events in Table 10 were also overlaid on the N686PA FDR longitudinal axis parameters plotted in Attachment 1, Figure A1.6.

2.14 Comparison of N686PA FDR data for DUT landings

A subset of the available N686PA FDR parameters for the accident landing and the three (3) previous landings at DUT are provided in Attachment 2, pages A2.2–29. Each page compares N686PA DUT landing data from the accident flight, 2 landings prior, 18 landings prior, and 23 landings prior. The parameter numeric suffix indicates the preceding flight leg number. The accident flight parameter names do not have a numeric suffix.

Longitudinal, lateral-directional, engine, and warning parameters are plotted as a function of time in four-page groups with 20, 10, 5, and 2 seconds per major division, respectively. The time scale for each data set was arbitrarily aligned using the GearWOW parameter transition point from 0 to 1. Anti-skid fault parameter activity is present during the accident landing as well as the 18th prior landing, also a DUT arrival.

3.0 SUMMARY

The normal and non-normal configuration landing distance scenarios evaluated indicate that N686PA should have had adequate performance capability to stop within the runway 13 LDA for all cases when both anti-skid control circuits were operative and for the case with one anti-skid control circuit inoperative and all engines operating at maximum reverse. In addition, N686PA should have been able to stop on the improved pavement surface near the RSA/blast pad transition point with one anti-skid circuit inoperative and AEO at GI thrust.

The Saab 2000 flight test normal landing, accelerate-stop, and rejected takeoff data indicate that a fully functional Saab 2000 can generate average deceleration rates ranging from 6 to 9 knots per second during the rollout segment with maximum wheel braking and operable anti-skid system. The stated 3-knot per second variation in average deceleration is a function of the landing flap, number of operating engines, engine thrust setting, and automatic flap retraction configuration.

With two anti-skid circuits active, the average Saab 2000 deceleration rate at flaps 20 (which becomes flaps 15 due to AFR after MLG touchdown) is expected to vary between about 7 and 9 knots per second during the transition and rollout segments for all engine thrust settings evaluated. For comparison, the average deceleration rate required to match the N686PA stopping performance during the accident transition and rollout segments was about 5 knots per second.

The FDR-based average deceleration for N686PA during the transition and rollout segments on the improved surface was about 4.7 knots per second. The corresponding CVR-based average deceleration was about 4.5 knots per second.

The aircraft performance group study results indicate that N686PA should have had the landing performance capability to stop within the runway 13 LDA or the RSA, given the documented aircraft energy state, MLG touchdown location, environmental conditions, and runway pavement and surface conditions.

4.0 ATTACHMENTS

Attachment 1: CVR events overlaid on runway 13 planform view and FDR time history plots
Attachment 2: Comparison of N686PA FDR data for the accident flight and three previous DUT landings